APRIL 1958

WELDING JOURNAL

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AND ANNUAL SPRING MEETING

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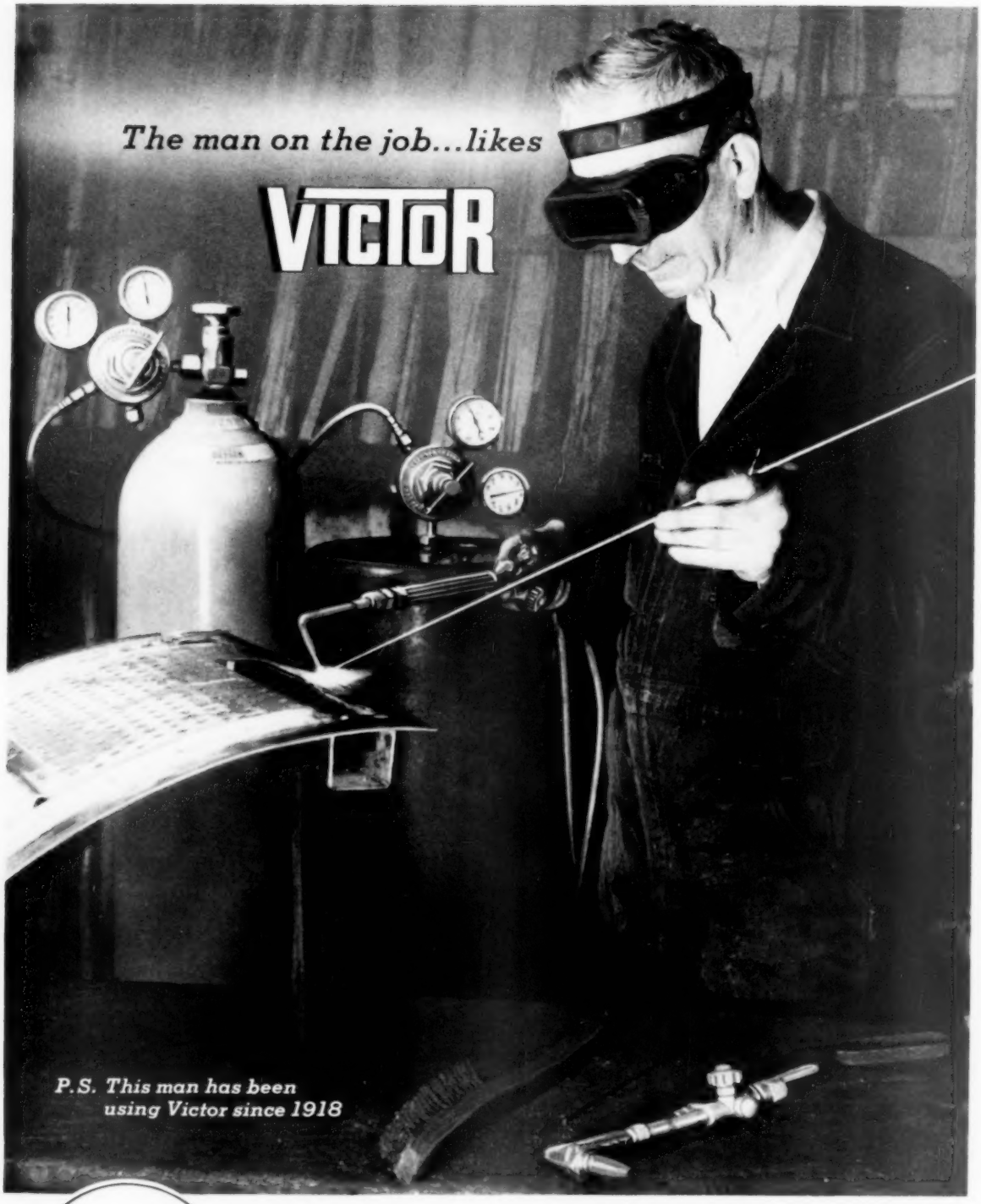

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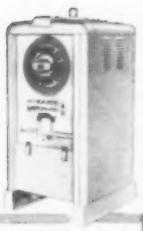

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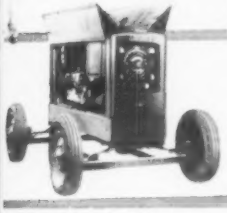

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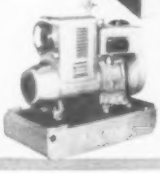

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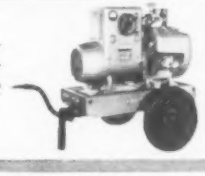

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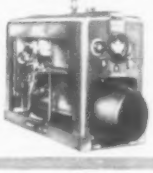

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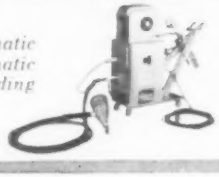

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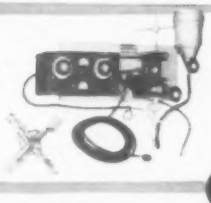

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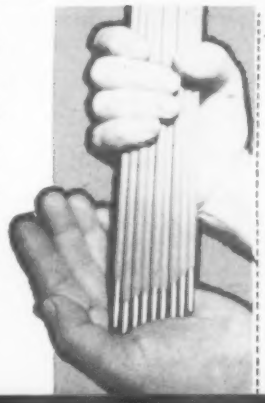

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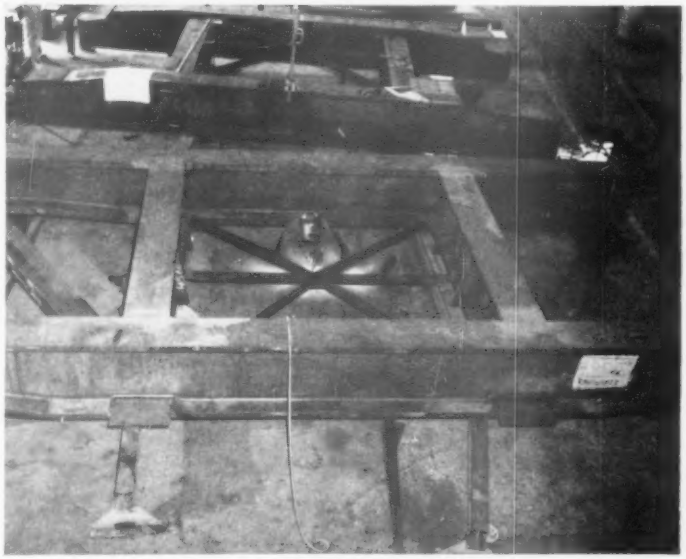

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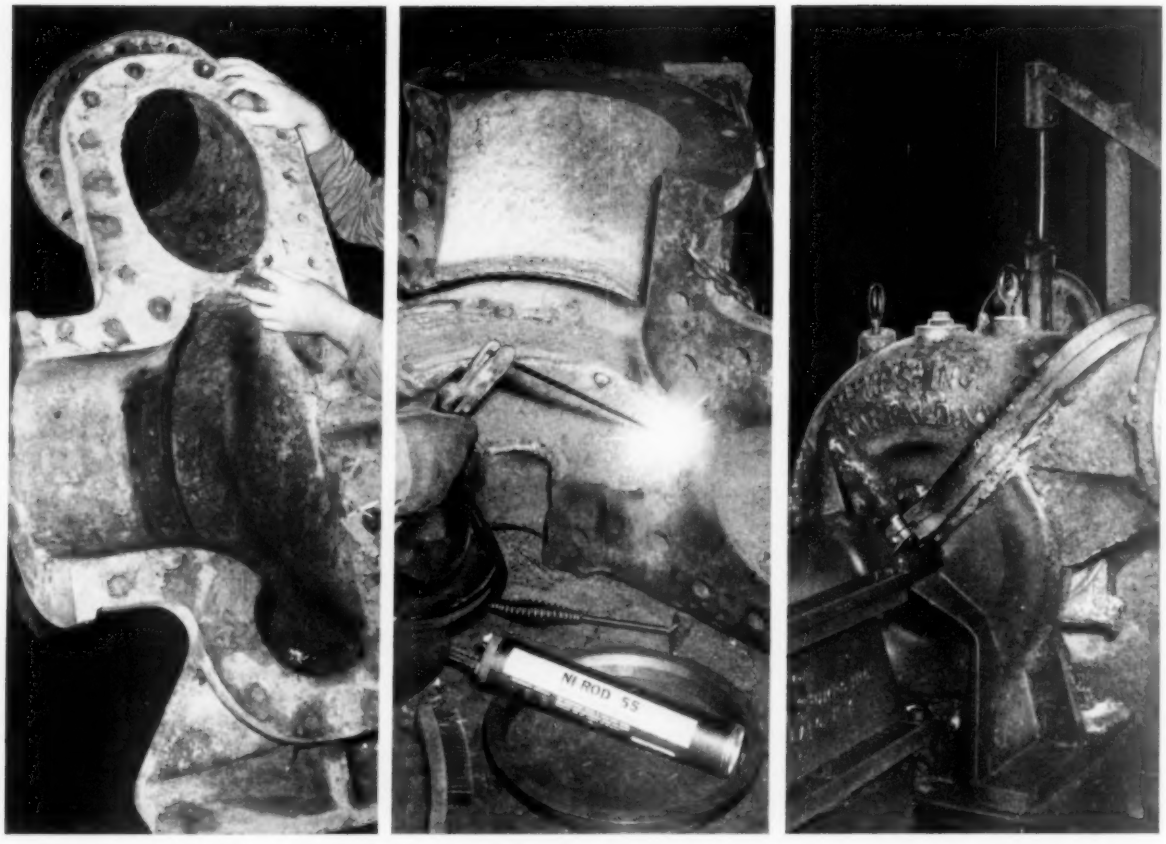

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THE WELDING CONVENTION AND YOU

Just five short years have gone by since the first complete All-Welding Exhibition and Convention was held in Houston, Tex., and yet, in that relatively short period of time, we of the AMERICAN WELDING SOCIETY have seen a dream come true. Yes, there were the conservatives in those early days who felt that such an undertaking was far too much for us to handle alone, but there were also those who had the optimistic view of the future in sufficiently clear perspective to see that this was not just a dream but something that time would prove to be very real.

Today, welding conventions can be and are being taken to many geographical locations throughout our country. Through this medium, everyone will have an opportunity of attending a technical meeting involving just welding "in" or "near" his own community. Here, we are able to exchange welding ideas and to solve our welding problems along with making new friendships and renewing the old. The 39th Annual Meeting and Sixth All-Welding Convention is designed to be such a meeting.

All we need to do is to look around to find that all phases of the welding industry are growing at a tremendous rate. Not only is welding being used on applications where it proves competitively to be the best method of fabrication, but there are many job requirements in today's fabrication problems that welding, and only welding, will satisfy. These realities are the seeds of an even better future.

As an industry, we are still young and growing rapidly as a society holding our own National Convention, we are similarly young and growing rapidly. We expect this pattern to continue and we look forward with confidence to the Annual Convention for all that it has to offer for today and tomorrow.

J. Edward Dato

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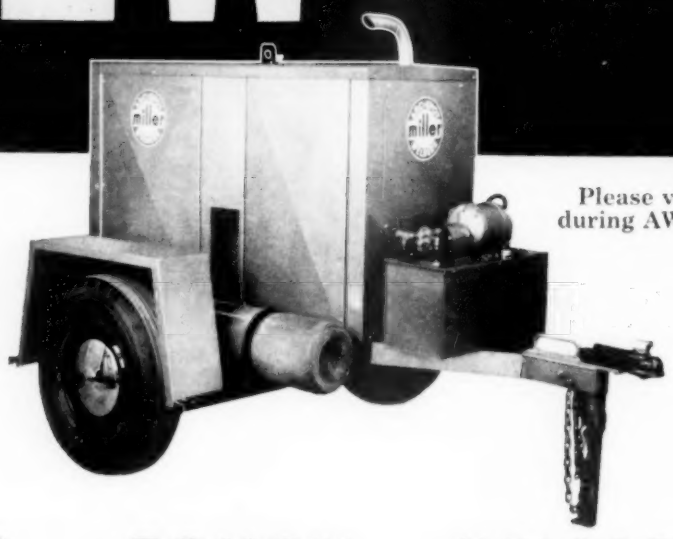

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Architectural sketch showing how structure will look when completed

DESIGN AND FABRICATION BY WELDING OF THE CARQUINEZ STRAIT BRIDGE

Experience with the Carquinez Strait Bridge indicates that members of the major truss spans can be fabricated satisfactorily by welding and that, if properly designed, can show economy

BY LEONARD C. HOLLISTER

SYNOPSIS. The new structure now being built by the California Division of Highways across Carquinez Strait is believed to be the first major cantilever truss-type structure to have its members fabricated by welding.

Leonard C. Hollister is Projects Engineer—Carquinez, California Division of Highways.

Paper to be presented at the 1958 AWS Annual Spring Meeting to be held in St. Louis, Mo., April 14th to 18th.

The new structure is being built 200 ft upstream from the existing bridge and will more than double the capacity of Interstate Highway Route 40 at this point. Being built parallel and close to each other, the geometry of the new one will match the existing one in span length and truss type. Both will consist of two main spans 1100 ft long with two anchor arms 500 ft and a central tower span of 150 ft, making the total length of the

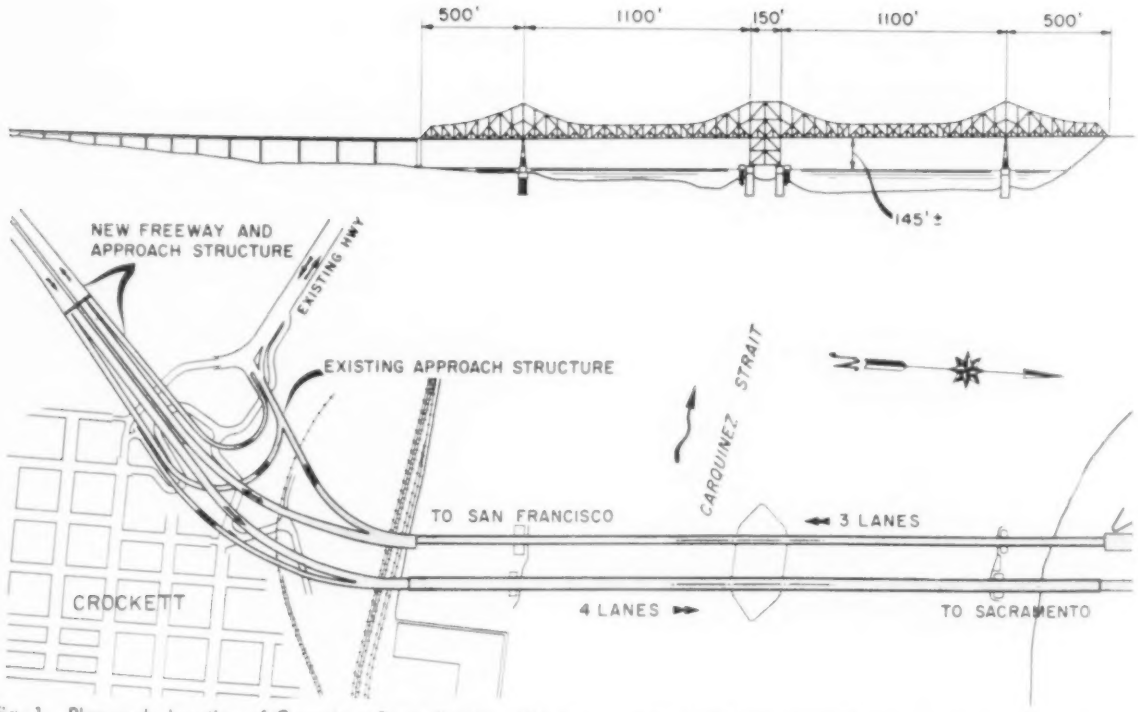
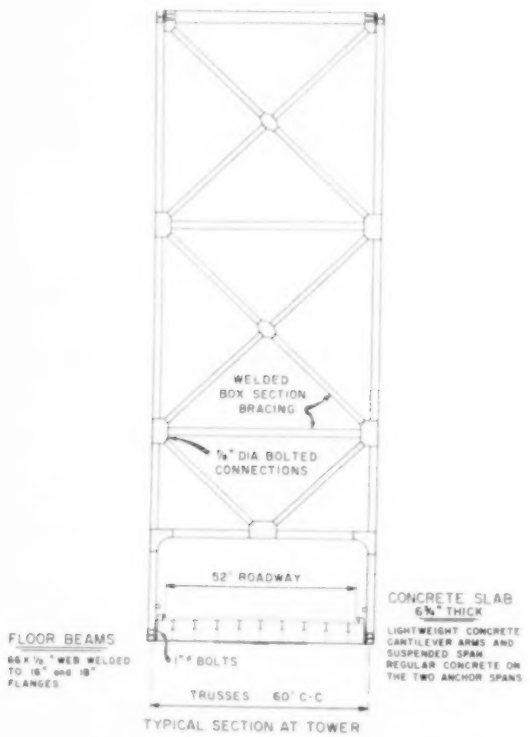


Fig. 1 Plan and elevation of Carquinez Strait Bridge. This is one of the four longest cantilever spans in the United States and one of the seven longest in the world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TYPICAL SECTION AT TOWER

Fig. 2 This is a typical section taken at one of the four towers. Railing is a 12- x 12-in. welded-plate box section, and the curb is made up as a welded-plate unit connected to and spanning between floorbeams

main spans across the Strait 3350 ft, as shown in Fig. 1. The existing structure is 42 ft center to center of trusses, while the new one is 60 ft as shown in the typical section at the tower in Fig. 2.

In addition to the main truss spans, there is an all-welded interchange and approach structure connecting to the south end. This involves 8,500,000 lb of all-welded steel girders in spans, for the most part, from 120 to 210 ft.

The existing bridge was open to traffic in 1927 and it represented, at that time, the best in structural design for long spans that had been established over many years of bridge building experience. The new structure represents the latest in modern design by making use of new steels, high-strength steel bolts for joint connections and fabrication by welding of the truss members.

The existing trusses have their members made up by the conventional riveting together of plates, angles, lacing bars and tie plates to form a composite structural unit. The new structure has its members fabricated by welding 3, 4 or 5 plates together.

The old made use of heat-treated eye-bars and some pin-connected joints for structural efficiency. The new accomplishes this by the use of the new, weldable, high-strength T-1 steel. This steel, which has a minimum yield strength of 90,000 psi, together with welded fabrication of members and high-strength bolted joints, has resulted in high structural efficiency. So, while the superstructure of the two bridges are almost identical in geometry, they differ quite radically in design.

The fabrication is now nearly complete and the erection is well under way. From the experience thus far gained, there is every evidence that fabrication of major truss spans by welding is economical and structurally sound and that quenched-and-tempered high-strength steels, such as T-1, have structural advantages that can be made to show economy in long span trusses.

The use of the new quenched-and-tempered high-strength steel made possible by welded fabrication indicates a possible savings of approximately $800,000. Other advantages hoped for by the use of welded fabrication are: more efficient use of

steel; simplification of design with greater leeway and choice in make-up; more economical maintenance of painted surfaces; and superior aesthetic qualities. The advantages of the high-strength bolted joints are improved structural efficiency and erection economy.

Design

Preliminary designs considered the use of A7 and A242 steels with the possibility that some heat-treated eyebars might be used. For a structure of this span length and roadway width, many of the truss members become very heavily stressed, thus requiring their fabrication from a rather large number of plates and angles if conventional riveted fabrication is to be used. Consideration was therefore given to fabrication of the individual members by welding since there appeared to be several advantages, such as simplicity of member make-up and more efficient use of materials resulting in possible over-all economy.

The experience gained by the Bridge Department of the California Division of Highways from the design, fabrication and construction over the past ten years of 242 all-welded bridge structures comprising the use of approximately 110,000 tons of steel, indicated that a satisfactory and economical job could be done. However, all of the previous structures using welded fabrication had been of the beam or girder type, and so far welded fabrication had not yet been extended to truss members. Extending the use of welded fabrication to truss members was therefore not done without considerable thought and study.

On the favorable side of welded fabrication were the following: experience with past welded fabrication indicated that there could be expected over-all economy in its use; design time and procedures could be considerably reduced; fabricating shops had greatly improved their welding techniques and were continuously turning out satisfactory jobs; the Division of Highways testing laboratory had done much to standardize testing and shop inspection procedures.

On the less favorable side were the following: this method of fabrication had not been used before on such a large major-sized truss; there was no engineering precedent for member make-up or standardization of details; some welded structures, including ships, tanks and bridges, had failed.

Extending the use of welding to major truss fabrication does break with past precedent. But the knowledge of welding and its techniques have made such outstanding advancements in the past few years that this step now appears timely and progressive.

After talking to various fabricators about member make-up, it was felt that satisfactory and practical details could be worked out.

Regarding the failure of a few welded structures, it was found that metallurgists and welding engineers had made such exhaustive studies, sparked by the failure of ships, that they now had a much better understanding of how to avoid such difficulties.

The chemistry, particularly the carbon content of the steels to be used, would be controlled and closely checked. Truss members would be relatively small in cross section compared to ships and tanks. Members would be straight, simple in design and free of any geometric notches. Further, fatigue, rates of application of load and operating temperatures would all be very favorable.

These facts, coupled with improved and reliable inspection methods, gave reasonable assurance that welded fabrication of truss members would be structurally reliable.

T-1 Steel Selected

Early preliminary designs, using single side plates for member make-up, of A7 and A242 steel and attempting to limit plate thicknesses to $2^1/_2$ in., indicated rather deep members for those that were more heavily stressed. These members were obviously quite stiff and produced rather prohibitive secondary stresses.

A steel with a higher yield and higher allowable working stress was therefore considered because such a steel would facilitate reduction in member depth and at the same time keep plate thicknesses for most members to $2^1/_2$ in. without multiple side plates.

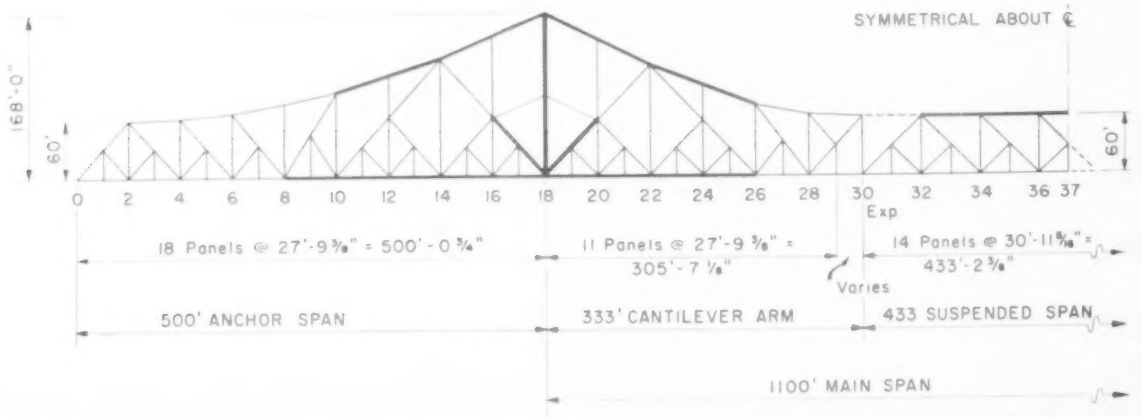


Fig. 3 Cantilever truss layout. Heavy lines indicate members designed for T-1 steel. Most other members were designed for A242

The new quenched-and-tempered T-1 steel was therefore considered. With the minimum yield strength of T-1 steel at 90,000 psi, a conservative working stress of 45,000 psi in tension and comparable allowable compressive stresses were used in the trial designs. The resulting trial member make-up for heavily stressed members indicated that they could be made reasonably shallow in depth and retain a simple member make-up without the use of multiple side plates. In addition there was a considerable reduction in steel tonnage which would result in economy if a satisfactory differential prevailed between the cost of A242 and T-1 steel. See Fig. 3 for truss layout and members finally designed using T-1 steel.

It was therefore decided that T-1 had sufficient potential qualities to make worth while a thorough investigation of its use for welded-truss members. This investigation was to include physical tests by the Division of Highways Laboratory.

Accordingly, 3000 lb of steel plates were secured from the producer in thicknesses of $\frac{1}{2}$–1 and 1$\frac{1}{2}$ in.

From these plates, numerous specimens of base metal and butt-weld joints were prepared. The various butt welds were prepared using semiautomatic shielded-arc, automatic submerged-arc and three types of manual low-hydrogen processes. Each sample was subjected to the following tests:

1. Radiographic inspection.
2. Standard tensile test for yield and ultimate strengths.
3. Fatigue tests by means of a loaded cantilevered rotating shaft.
4. Standard free and side-bend tests.
5. Charpy impact and Rockwell hardness tests.
6. Metallographic examination.

A complete report on the above tests was prepared and the more important conclusions contained therein were as follows:

1. Structural T-1 steel may be satisfactorily welded for structural purposes using both automatic and manual processes, providing the welding procedures are carried out properly.

2. A joint efficiency of 95% for structural T-1 steel welded joints can be obtained if based on the usually specified mechanical properties of T-1 steel for structural use.

3. Narrow tolerances in operating procedures are necessary for the consistent production of satisfactory welds of T-1 structural steel. This will necessitate rigorous prequalification of all welding operators and procedures and will allow no deviation from established procedure.

4. The more ductile E10016 and E11016 electrodes produced butt joints with strengths approximately equal to those provided by butt joints welded using the harder E12015 electrodes. It is considered that the use of E100 and E110 series of low-hydrogen electrodes will result in an over-all more satisfactory structural weld than can be made by using the E120 low-hydrogen electrodes.

Table 1 — Typical Comparative Chemicals

	T-1		A-242		A-373		A-7	
	Specified	*Typical*	*Specified*	*Typical*	*Specified*	*Typical*	*Specified*	*Typical*
Carbon	0.10-0.20	0.17	0.22 max	0.22	0.26 max	0.19		0.25
Manganese	0.60-1.00	0.90	1.25 max	1.16	0.50-0.90	0.84		0.54
Phosphorus	0.04 max	0.018		0.013	0.04 max	0.013		0.014
Sulfur	0.05 max	0.022	0.05 max	0.025	0.05 max	0.021	0.05	0.029
Silicon	0.15-0.35	0.23		0.08	0.15-0.30	0.21		
Nickel	0.70-1.00	0.81						
Chromium	0.40-0.80	0.48		0.04				
Molybdenum	0.40-0.60	0.50						
Vanadium	0.03-0.60	0.04		0.04				
Copper	0.15-0.50	0.40		0.23				
Boron	0.002-0.006							

Table 2 — Typical Comparative Physicals

	T-1		A-242		A-373		A-7	
	Specified	*Typical*	*Specified, 1$\frac{1}{2}$ in.*	*Typical, 1$\frac{1}{2}$ in.*	*Specified*	*Typical*	*Specified*	*Typical*
Yield point, psi	90,000	110,700	46,000	50,960	32,000	40,950	33,000	36,120
Ultimate strength, psi	105,000	125,300	67,000	81,060	58,000 75,000	71,920	60,000 72,000	65,790
Elastic ratio, %		88.5		62.5		56.5		55
Elongation in 2 in., %	18	22		29	24	33	24	36
Elongation in 8 in., %		12	17.5	26.5	19.5	23	21	28
Reduction of area, %	55	65		65		57		60
Charpy keyhole impact test at 15° F, ft-lb		31		24		23		23
Transition temperature, heat-affected zone, 0° F		−30		−25		+10		+10

NOTE: Charpy-keyhole impact and transition-temperature tests were made on metal from the heat-affected zone of the as-welded specimen. The transition temperature and impact test results shown are the worst of one to three specimens tested.

Fig. 4 This sketch shows four different methods considered for fastening the corners of box-section members. Detail 4 was the one chosen as the most practical and least costly

5. Wherever possible, mechanically-guided and controlled processes should be used when flame cutting T-1 steel. These operations should be so adjusted and controlled as to provide smooth edges free from zones of excessive hardening.

6. T-1 steel flame-cut edges which are to be welded should be mechanically treated to remove hardened metal, oxides, scale and surface irregularities in order to prevent oxidized metal and slag from being trapped in the weld metal during welding operations.

7. When flame-cut edges are exposed, as in the flanges of fabricated members, care should be exercised to keep such edges smooth and even, and free from uneven hardnesses resulting from the flame cutting. It will be necessary that excessively hardened metal, sharp corners and abrupt surface irregularities be removed.

It will be noted that T-1 steel has a very high elastic ratio, with the minimum yield at 90,000 psi and the minimum ultimate at 105,000 psi giving an elastic ratio of 86% and higher. The AASHO specifications do not limit the ratio of yield to ultimate strength. The AREA specifications, however, have since 1935 limited this ratio to 70%. There was, therefore, concern in the minds of some structural engineers regarding this elastic ratio quality of T-1 steel. It is felt by some that a larger spread between yield and ultimate provides an additional factor of safety for unforseeable overloads. This appears to be a controversial point among structural engineers; fortunately, however, a long-span highway structure is not likely to be subject to any great overloads due to live load.

A more important consideration would therefore appear to be the notch toughness or transition-temperature characteristics of the steel. T-1 steel, being a quenched-and-tempered steel, has excellent notch toughness and low transition-temperature qualities, and since it exhibits sufficient elongation ductility to produce the desired toughness, it was considered to be a completely reliable steel for the use intended.

Tables 1 and 2 compare the chemical and physical qualities of the T-1 steel with those of A242, A373 and A7 steels. The results shown are those taken from tests of the various plates as actually used, and the specified amounts are those called for in the specifications. The Charpy-keyhole impact tests were made at 15° F which is slightly lower than the lowest recorded temperature at the bridge site of 19° F.

Member Make-Up

Three general shapes of member make-up were decided on as follows: the I section for floor beams and approach girders; the H section for tension truss members, and the box section for compression members. The I section for girders and floor beams offered no problems as these were made in accordance with established practice, that is, with two flange plates and a connecting web plate. The H sections for tension members offered no problems as this would again consist of two flange plates and a single web.

The box section for compression members had very little precedent to follow as to the best detail for fastening the plates at each corner of the box.

Figure 4 shows the four methods considered for welding the corners of the box sections. Joint No. 4 was considered structurally satisfactory and the most workable. It was therefore considered to be the most economical to fabricate and was the detail selected.

Allowable Working Stresses

The allowable working stresses used in the design were as shown in Table 3 and the following formulas.

In addition to the limiting stresses given in Table 3, plate thicknesses were further limited to the following (in several of the compression members using T-1 steel, the allowable unit stress was determined by plate thickness):

Main plates supported two sides

$$\frac{b}{t} = \sqrt{\frac{15{,}350{,}000}{s}}$$

Web plates connecting main plates

$$\frac{b}{t} = \sqrt{\frac{24{,}220{,}000}{s}}$$

Plates supported on one side

$$\frac{b'}{t} = \sqrt{\frac{2{,}187{,}000}{s}}$$

Perforated cover plates

$$\frac{b}{t} = \sqrt{\frac{37{,}500{,}000}{s}}$$

where

b = unsupported width of plate, in.
b' = distance from support to free edge of plate.
s = axial unit stress, psi.
t = plate thickness, in.

Table 3—Allowable Working Stresses

Type of Steel	*Tension*	*Compression*
A_7 and A_{373} (A_7 to be used for less than 1 in.)	18,000	$15{,}000 - 0.25\,(L/r)^2$
A 242 (3/4-in. plate and under)	27,000	$22{,}000 - 0.56\,(L/r)^2$
A 242 (3/4 to 1 1/2 in.)	24,000	$20{,}000 - 0.46\,(L/r)^2$
A 242 (over 1 1/2 to 2 in.)	22,000	$18{,}000 - 0.39\,(L/r)^2$
T-1	45,000	$36{,}000 - 1.75\,(L/r)^2$

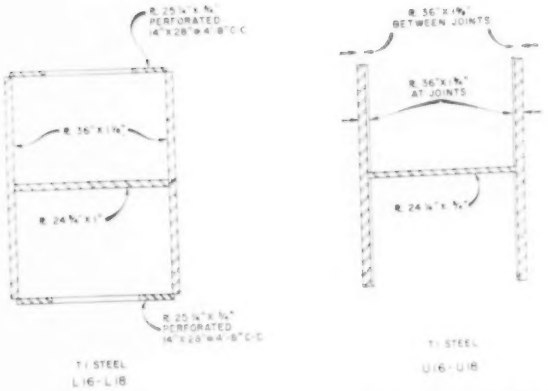


Fig. 5 Detail of five-plate compression member L16L18 and three-plate tension member U16U18. These are typical except for size of plates for the five-plate box sections and the H-sections used throughout the truss

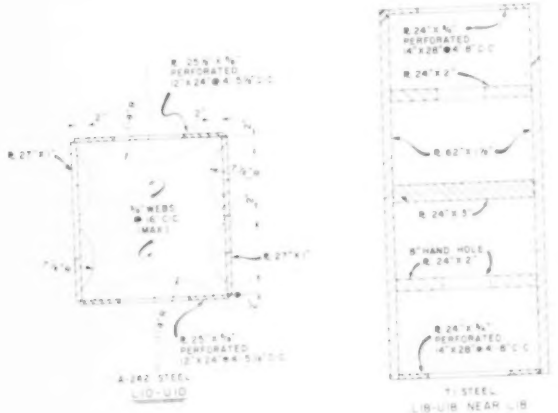
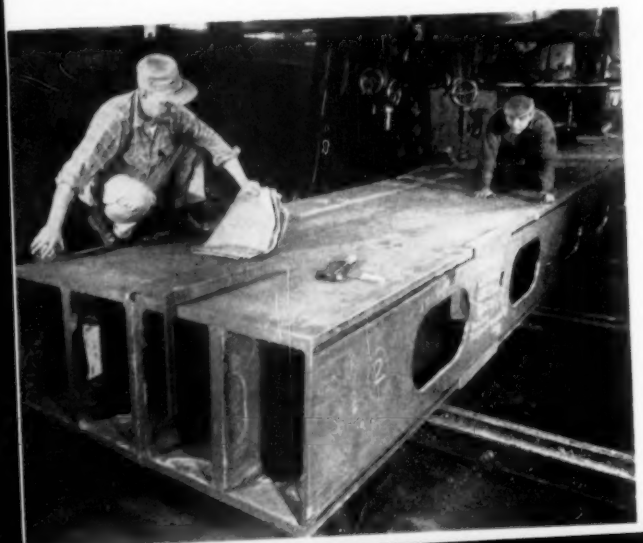


Fig. 6 This shows a detail section of L10U10 which is a typical 4-plate box section with diaphragms. Also a section of the heaviest truss member at the lower portion of L18U18

Fig. 7 Fabricated column section L18M18 (lower part of L18U18) at the Ambridge plant. Visible are double-J welds for the three interior webs and single-J welds for the outside cover plates. Make-up of this section is shown in Fig. 6



The allowable unit stresses for tension and compression for A7, A373 and A242 are those recommended in the AASHO Standard Bridge specifications. The allowable working stress for T-1 in tension was based on a minimum factor of safety of two. The allowable compressive stress for T-1 steel was made to conform to the Secant Column Formula with a factor of safety of two, and agrees very closely with it up to an L/r ratio of 75. Above $L/r = 75$ the formula of $36{,}000 - 1.75\,(L/r)^2$ gives more conservative values for allowable working stresses than does the Secant Formula.

Using these unit stresses there follows a theoretical comparison between T-1 and A242 steel for member U16U18 which is a tension member.

	T-1	*A242*
Design load, kips	5031	5524
Working stress, psi	15,000	22,000
Make-up (at joints)	2 plates, 36 x 5/8 1 plate, 23 1/2 x 5/8	2 plates, 36 x 5/8 1 plate, 19 1/2 x 2 1/2
Make-up (between joints)	2 plates, 36 x 1 1/8 1 plate, 24 1/2 x 5/8	2 plates, 36 x 2 1/2 1 plate, 21 1/2 x 2 1/2
Average weight per ft, lb	415	895
Total weight, lb.	24,450	52,900
Moment of inertia, in.^{4}	10,692	21,384

Figure 5 shows the make up of U16U18 and also a comparable compression member L16L18.

Tension members which were of the H section required an increase in thickness of side plates near each joint to take care of the loss in net section where holes are drilled for connections. Thickness of side plates were increased for a distance of 12 in. past the joint at which location a butt weld to a thinner plate was made. This made possible a considerable reduction in the total tonnage of steel required.

A comparison of compression member L16L18 would indicate similar reductions in weight.

Some compression members were made of five plates, one of which acted as a horizontal web plate. Some of the lighter compression members and bracing struts were made of only four plates eliminating the horizontal web. For the four-plate compression members and struts, ⅜-in. diaphragm plates were welded in place at variable spaces. The function of these plates was to facilitate accurate fabrication free from twists or wind. Cover plates for compression members were all of the perforated type.

Figure 6 shows a four-plate compression member at L10U10 and the heaviest truss members at the towers L18U18 composed of seven plates. Figure 7 shows L18M18 after fabrication in the shop. L18M18 is the lower portion of L18U18.

When bids were received in November 1955 for the superstructure of the main spans, they were based on the pound price for the three grades of steel T-1, A242 and A7. For bidding purposes A7 and A373 were to carry the same price.

Following is the low bid for the structural-steel items:

A7	12,880,000 lb at 0.2417	=	$3,113,096
A242	10,740,000 lb at 0.2752	=	2,955,648
T-1	5,820,000 lb at 0.3476	=	2,023,032
	Total structural steel		$8,091,776

These bid prices did not include the cost of sandblasting and painting structural-steel members, which item was a lump sum bid of $735,000.

It is realized that these bid prices do not necessarily indicate the true difference in cost between T-1, A242 and A7 steel for the final fabricated and erected product. These prices might vary with the fabricator, location of shop, freight rates and many other factors. However, using these unit bid prices and comparable make-ups for members from T-1 and A242 steel, it appears that the savings effected by the use of 5,820,000 lb of T-1 steel in lieu of a larger amount of A242 steel was in the neighborhood of $800,000.

The savings effected by the use of welded vs. riveted fabrication are difficult to analyze. It can be said, however, that there is more efficient use of material particularly in the tension members, because it is necessary to add additional metal for loss of net section in the vicinity of the joints only. In addition it makes possible the use of T-1 steel which is not available in angle shapes that are required for riveted fabrication.

Welded fabrication effects simplification and gives the designer greater leeway in the choice of member make-up; in addition, it reduces design time and engineering costs.

Examination of some of the comparable riveted members of the existing structure with the welded members of the new structure results in the following typical comparison.

L16L18 of the existing structure is made up of 14 component parts consisting of 4 angles, 8 side plates and 2 cover plates with the corresponding material at splices. This member required the punching or drilling of 3600 holes and the reaming and riveting of 1000 holes in the assembled member.

L16L18 of the new structure was made up from 5 plates fastened together by welding with 340 ft of $^{3}/_{8}$-in. fillet welds.

In making this comparison of the riveted vs. the welded details for these heavy members, it might easily lead to the erroneous conclusion that fabrication of the welded member would be simpler and therefore more economical.

The factors that appear in riveting that do not occur in welding are the punching, drilling, reaming and riveting. The fitting up of the member into a structural unit after this portion of the work is done is quite easy.

The factors that appear in welding that do not occur in riveting are the jigging up of the plates in preparation for the welding. After the plates are securely clamped in the jig, then the member must be positioned for vertical automatic fillet welding. The corners of the plates are then fastened together by fillet welds which requires preheating. Following the completion of each run of fillet weld the member must be repositioned and the welding repeated.

After welding is completed, there is a possible straightening cost to bring the member within specified tolerances. Straightening costs vary considerably with condition of the plate material received, the make-up of the member as to size and plate thickness, and as to symmetry. A considerable amount of straightening work can be eliminated by the proper sequence of welding, care in the location and temperature of preheating and adequate clamping in jigs.

Therefore, while the welding operation alone is less costly in materials, labor and overhead than the riveting, the jigging, positioning, preheating and straightening operations can be quite costly.

It would appear to follow that, for the present, if welding of members for a major truss is to show over-all economy in comparison with a riveted design, it must be done in the savings of material rather than in any economy of the fabricating process itself.

It might well be pointed out, however, that riveting has been the standard method of fabricating truss members and girders for many years. During those many years, new and improved riveting and fabricating equipment has been developed for mass production by riveting, which has made for efficiency and reduced fabricating costs. It stands to reason then that, as welded fabrication becomes more predominant, new and improved equipment will be developed for the mass production methods of jigging, positioning, preheating and straightening, making the fabrication by welding more efficient, resulting in reduced costs.

High-Strength Steel Bolts

From a review of the rather extensive research on riveted and bolted joints by the Engineering Foundation, it was concluded that field connections by high-strength steel bolts would produce a more structurally satisfactory job. Both bolted and riveted joints appear to derive their initial safety from plate friction rather than from bearing or shear on the bolts or rivets. The bolted joint properly designed produces this desired friction in a more direct and reliable method than do rivets.

It was also hoped that the field bolted joints would show some economy over riveted joints. The bolt material costs are higher than the rivet material, but the labor in bolting a joint is much less than the labor involved in riveting. In addition, efficient riveting crews are much more difficult to secure or train.

From information thus far gained from the erection procedures on the main Carquinez Bridge, it appears that one bolting crew consisting of two men can equal the erection rate of one riveting crew of four men. So far the bolting crews have been able to keep pace with erection which is very important in meeting erection schedules. It is the concensus that it would be difficult to find a sufficient number of trained riveters to keep pace with erection were the joints riveted.

The fabricator was given the option in the specifications of using either shop rivets or shop bolts. The fabricator chose shop bolts because it was felt that they would facilitate fabrication of the high-strength mate-

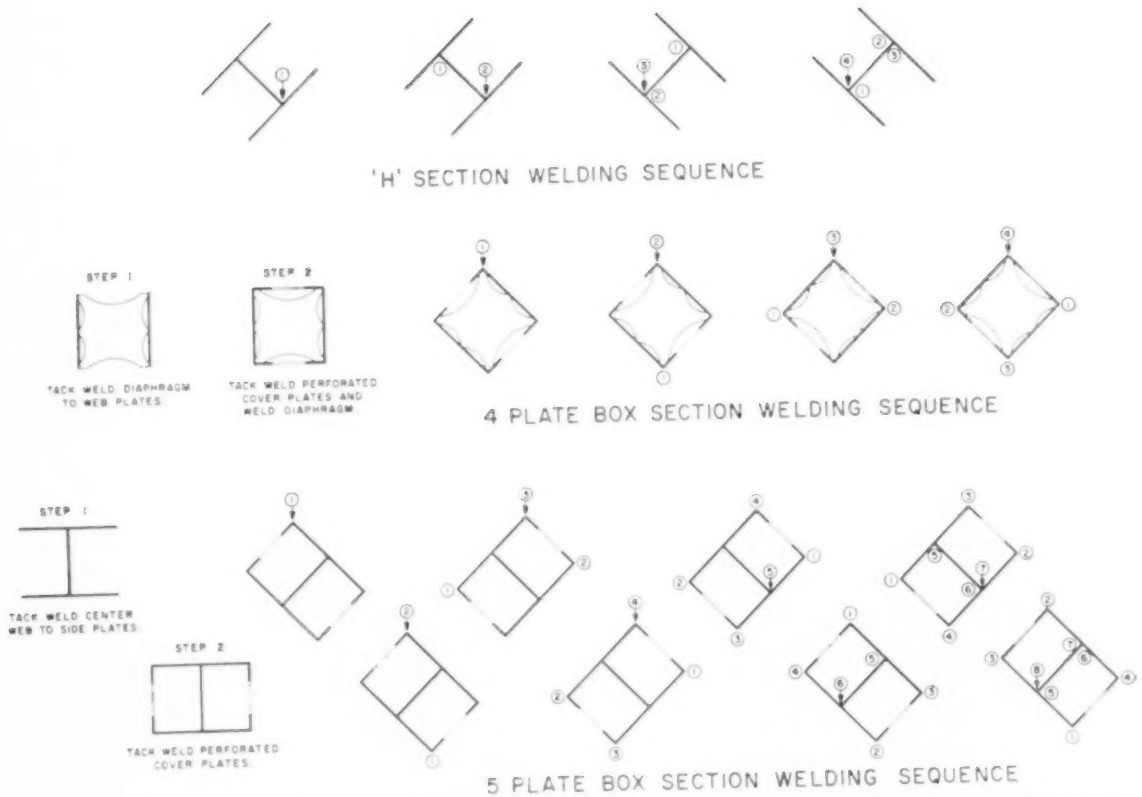

'H' SECTION WELDING SEQUENCE
STEP 1
TACK WELD DIAPHRAGM TO WEB PLATES
STEP 2
TACK WELD PERFORATED COVER PLATES AND WELD DIAPHRAGM
4 PLATE BOX SECTION WELDING SEQUENCE
STEP 1
TACK WELD CENTER WEB TO SIDE PLATES
STEP 2
TACK WELD PERFORATED COVER PLATES
5 PLATE BOX SECTION WELDING SEQUENCE

Fig. 8 This sketch shows the welding sequence used for H-sections, the 4-plate box sections with diaphragms and the 5-plate box-section truss members

rial used in gusset and splice plates and member make-up.

The specifications called for the gusset and splice plate material to be the same as the member with the highest-strength steel entering the joint. For this reason, most main gusset and splice plates were of either T-1 or A242 steel. Gusset plates were either $^{3}/_{4}$ or $^{7}/_{8}$ in. thick with some joints having double gusset plates. Maximum splice plates were 1 in. in thickness.

In drawing this material up to a tight-fitting joint, there was therefore considerable advantage in using the high-strength bolts. The first few bolts of a joint could easily be tightened after the remaining bolts had completed the drawing together of the several layers of plates.

All truss joints were fastened with 1-in. diam bolts except L18U18, the main vertical tower member, where $1^{1}/_{4}$-in. diam bolts were used. All sway bracing joints were fastened with $^{7}/_{8}$-in. diam bolts.

Bolts were tightened with impact wrenches calibrated to produce the minimum torque recommended by the Engineering Foundation Research Council on Bolted Structural Joints. Bolts were tested by inspectors using calibrated torque wrenches testing approximately every fourth bolt. Should any loose or unsatisfactory bolts be found then all the bolts of that joint would be tested. The testing was done by a two-man crew which followed closely behind the erection crews before staging at the joint had been removed. It is believed that testing for a satisfactory bolt is much more positive and reliable than testing for a sound rivet.

Approach Spans

The 1800 ft of approach spans on the south end of the main bridge also form an interchange structure allowing ingress and egress to the freeway at this point.

This structure consists of welded-steel girders supported on reinforced-concrete piers. Spans vary from 120 ft to a maximum of 210 ft. There were 4262 tons of steel in these girders, of which 2514 tons were A242 and the remainder A7.

These girder spans are quite typical of the welded-girder highway structures being used in California and other states in connection with the highway program.

The 210-ft girders were made up of a web plate 144 x $^{3}/_{4}$ in. with top and bottom flange plates 24 in. wide, with four variations in thickness which were $2^{1}/_{2}$, $2^{1}/_{4}$, $1^{1}/_{2}$ and 1 in. going from the center to the end of the girder. Vertical stiffeners 10 x $^{5}/_{8}$ in. spaced at about 6 ft 4 in. centers were used on one side, and a 6- x $^{1}/_{2}$-in. horizontal stiffener located 2 ft 5 in. below the top compression flange was used on the other side to stiffen the 144- x $^{3}/_{4}$-in. web plate.

Because of the fact that the girders for the most part were to be erected about 120 to 130 ft above ground and were too long to erect in one piece, field splices consisting

of a bolted web and welded flanges were permitted by the design plans. This was a departure from standard practice done as an experiment to see if it facilitated field erection under conditions where falsework was difficult to construct.

The Bethlehem Pacific Coast Steel Co., subcontractors for Pete Kiewit Sons' Co. on the structural steel fabrication and erection of the approach spans, elected to use the bolted web splice.

The conclusions reached are that from an overall standpoint considering extra shopwork and bolt costs the work saved in field erection and splicing did not warrant the departure from the standard practice. It therefore appears that the only condition under which this type of field splice might be justified would be at a location where falsework would be prohibitive.

From this it can be concluded that under normal circumstances the fully-welded girder splice is preferable from both a design and erection standpoint.

Fabrication

The superstructure of the main bridge was fabricated by the American Bridge Division of the United States Steel Corp. at their fabricating shops in Gary, Ind., Ambridge, Pa., and Orange, Tex.

Before the start of fabrication of the main truss members, the fabricator gave considerable study to the whole procedure problem. This included the determination of the sequence of welding for the various types of members; plate preparation such as straightening, joint shaping and edge planing; jigging up of the several plates forming a member, positioning equipment and methods; preheating methods; and tests for qualification of welders, welding equipment and the type of rod and flux to be used.

To thoroughly test these procedures, and make revisions if necessary, it was planned to fabricate six pilot sections with the idea that these members would become a part of the finished product for use in the bridge structure if satisfactory results were obtained.

Two pilot members chosen were of T-1 steel. One of these was top cord tension member U10U12 with three plates forming an H section. The other T-1 steel member was L18M18, the lower portion of L18U18, the vertical member at the tower and the heaviest compression member in the truss. A section of this member is shown in Fig. 6, and a picture of the member in the fabricating shop is shown in Fig. 7.

Three pilot members of A242 steel were also fabricated. The members chosen for this trial run were L4L6, U4U6 and L32L34.

L4L6 is a five-plate box-section compression member; U4U6 is a three-plate H-section tension member; L32L34 is a tension member for the completed structure but a compression member during erection and is a four-plate box section.

Member L2L4 made of A7 steel was selected for the sixth pilot member. This member is in tension for dead load but reverses to compression for certain positions of live load. This member is a five-plate box section.

Fig. 9 Welding and preheating an H-section member. These members were more difficult to fabricate than the box-section type because there was no built-in restraint against flange-plate warpage. Work being done at the Ambridge plant

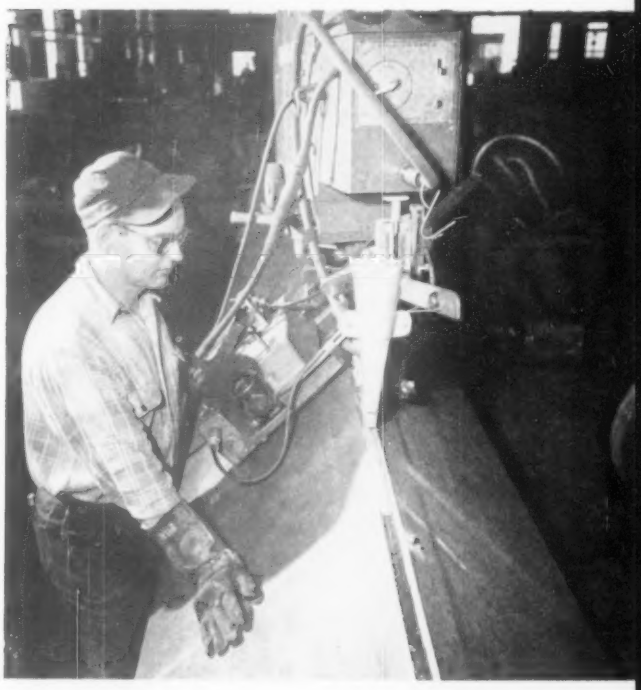


Fig. 10 Box-section member being welded at one corner. A single-pass fillet weld will be made from end to end, after which member will be repositioned for welding another corner of box section

Welding Sequence

Figure 8 shows the welding sequence for the H sections, and the four- and five-plate box sections.

The first operation was to perform all butt welds so as to make each plate full length of member. Each

Fig. 11 Interior web plate of a box-section member being welded at the Ambridge plant

butt weld was radiographed for inspection and approval.

After butt welding the plates, they were then placed in jigs and fastened with tack welds. Following this, the welding procedure was as shown in Fig. 8.

Figure 9 shows the welding and preheating operations for an H-section member.

Figure 10 shows the corner fillet-welding process for a box-section member.

Figure 11 shows the fillet-welding procedure for the interior web of a five-plate box section.

Single-pass fillet welds were used on all truss members except vertical L18U18 and the supporting tower members. On the heavy sections of these members, single and double welds were used with multiple passes. Here the member was positioned for each successive root pass and then repositioned for every two passes thereafter.

Preparation of flame-cut edges to be welded consisted of smoothing and grinding where necessary on A7 and A242 steel. Flame-cut edges of T-1 steel to be welded were edger planed to remove hardened metal, oxides, scale and surface irregularities.

The six pilot sections were found to be very satisfactory and fabrication proceeded on the basis of experience gained from fabrication of these members with but very few minor changes.

The fabricated pieces have been received at the job true to dimensions and free from twist or wind. Erection is proceeding at a rapid pace and all members are fitting with very good accuracy.

The approach span girders were fabricated at the Alameda, Calif., plant of the Bethlehem Pacific Coast Steel Co.

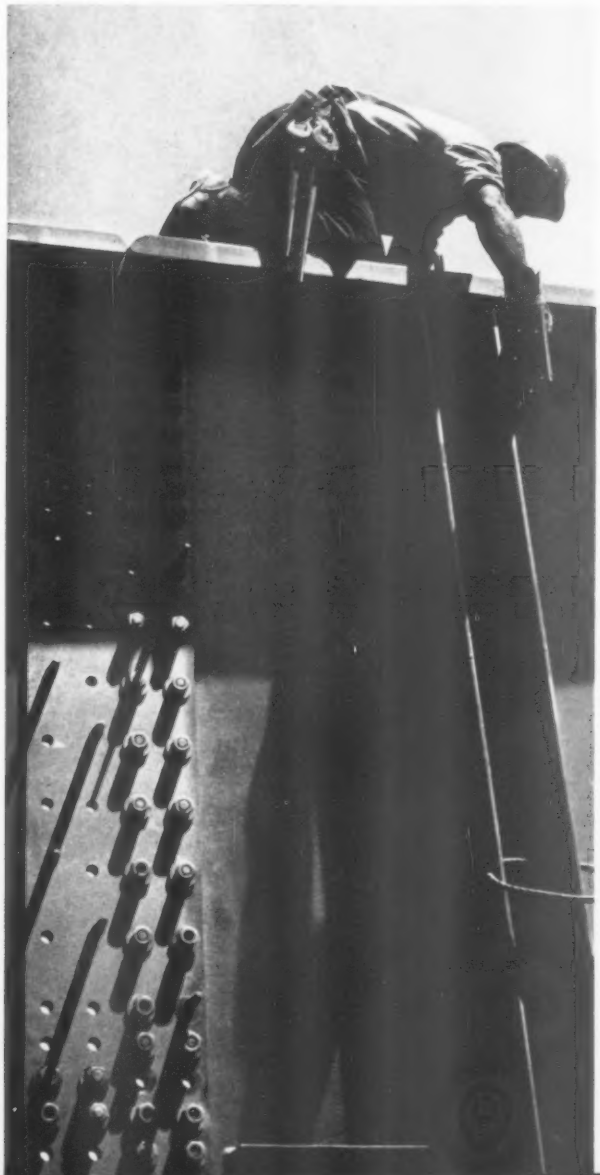
These girders were fabricated from A242 steel plates

Fig. 12 Fabrication of a section of one of the approach girder spans in the Alameda plant of the Bethlehem Pacific Coast Steel Co. Flange and web plates have been butt welded and web has been tack welded to flanges. Preheating and fillet-welding operations are under way

by first butt welding all web and flange plates to the desired length of 70 to 84 ft. The plates were then accurately placed in a newly devised welding jig and securely held in position by jacking yokes. The entire jig could be rotated for positioning the member for flat fillet automatic welding. Figure 12 shows the shop welding and preheating of these girders.

Girder sections were shipped to the job in maximum lengths of 84 ft and erected on the piers and temporary steel towers. Field splices were then made with girders in position by loosely bolting the web splice plates and dogging the heavy flange plates in correct position for butt welding. Figure 13 shows preparation in the field for welding flange splices, with web splice partially bolted.

Fig. 13 Field erection of approach girder span by Bethlehem Pacific Coast Steel. Bolted web splice was left loose until welded flange splices were completed. This picture shows preparation under way for start of welded flange splice



Maintenance

At the present time it costs approximately $60,000 per year to paint and maintain the steel surfaces of the existing Carquinez Bridge.

Smooth steel surfaces are easier to clean and paint and they retain their painted surface intact much better than rough surfaces, sharp edges, rivet heads and bolts. The new Carquinez Bridge with its maximum percentage of smooth steel surfaces and with the minimum percentage of sharp edges, re-entrant angles, and bolt heads should be much easier to maintain.

The bolt heads and nuts with their six sharp corners may be more vulnerable and difficult to maintain than rivet heads. However, maintenance as a whole should show economy over the many years of life expectancy for the structure.

Aesthetic Qualities

The smooth clean surfaces of the members of the new bridge in comparison to the rough, hit or miss random surfaces of the old structure, produce definite superior aesthetic qualities. The new structure imparts a greater feeling of structural stability and security whether viewed from close range on the deck or at a distance.

There is no question but what a well-designed riveted structure can impart this feeling of strength and security also. It is important to know, however, that this aesthetic quality can be imparted by the smooth welded surface with the rivet heads usually associated with structural steel absent—and because the design has greater choice in make-up, strength and security can be imparted with less materials and greater economy.

Conclusions

It can safely be concluded from the experience of the Carquinez Bridge that members of major truss spans can be fabricated satisfactorily by welding and that, if properly designed, can show economy. One point should be made clear however, and that is, if welded fabrication is to be used, the plans should be so designed. It is seldom, if ever, satisfactory to prepare a design based on one type of fabrication and permit changing to another during construction.

The use of T-1 steel is a very satisfactory and reliable steel for use in major truss spans, if welded fabrication is to be used. Properly designed, it can be made to show economy where used in many highly stressed truss members.

Acknowledgments

The author wishes to acknowledge with thanks, the suggestions and information furnished by the following: J. D. Rollins, vice president engineering, American Bridge Division of the United States Steel Corp.; H. A. Schirmer, contracting manager of the Bethlehem Pacific Coast Steel Corp.; John L. Beaton and Paul G. Jonas of the Division of Highways Testing Laboratory; F. W. Panhorst, assistant state highway engineer Bridges, and Roger Sunbury, Division of Highways, Bridge Department.

Aluminum welding cable in use at Gladding & Hearn Shipbuilding Corp.

ALUMINUM WELDING CABLE

Advantages associated with the use of aluminum welding cables are discussed by the author

BY J. G. STONE

SYNOPSIS. Aluminum welding cable was introduced to the welding trade about five years ago and has since gained widespread acceptance. With an electrical conductivity of 61% of copper, the aluminum conductor must be approximately 27% larger in diameter than a copper conductor for the same conductance, but will weigh only half as much. With the addition of an insulating jacket, the average aluminum welding cable will be 34% lighter than a copper cable of the same conductance and will operate cooler because of its increased radiating surface. The excellent electrical characteristics, light weight, ease of handling and reduced operator fatigue, combined with low cost, make it ideally suited for manual arc-welding operations.

Improvements in manufacturing techniques have resulted in constant improvements in the performance and service life of aluminum welding cable, while research by cable and accessory manufacturers has resulted in the development of accessories, such as lugs, connectors and electrode holders which are designed for use with aluminum welding cable to give superior service.

History

One of the most important accessories in the field of welding is the cable which conducts the electrical current from the power source to the welding head or electrode holder. This cable must be tough and durable, must be capable of carrying electrical currents of high magnitude, and must be extremely flexible to permit easy manipulation of the electrode. The various natural and synthetic elastomeric jackets in use today provide protection to the cable against a wide range of mechanical and chemical abuse. Conductor sizes are varied according to the current carrying requirements. The needed flexibility is accomplished by building the conductor of a large number of very small bare strands or wires.

Until about five years ago, almost all welding cable was made with copper conductors. The good flex life and high electrical conductivity of copper made it ideally suited to welding cable use. The excessive weight of copper cable, however, has always been a problem in manual arc welding, contributing greatly to operator fatigue and reduced efficiency, and where long leads are used it is often necessary to provide a welder with additional help while moving or transporting the welding lead.

Although aluminum has been used extensively as an electrical conductor in bare overhead transmission lines for nearly sixty years, there was no significant

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production of insulated aluminum conductors in this country previous to the end of World War II. Shortly after World War II, however, various aluminum producers and cable manufacturers initiated research programs directed toward increasing the use of insulated aluminum conductors in the electrical field. This was a natural outgrowth of the ready availability of aluminum, and its excellent electrical characteristics and low cost. These programs were further accelerated by an increasingly unstable copper market. Since weight is an important factor in manual arc welding, it was natural that welding engineers, equipment suppliers and cable manufacturers should show increasing interest in light-weight welding cables made with aluminum conductors. After considerable development and testing, aluminum welding cable was introduced in limited quantities about five years ago, and has since shown a steady increase in usage.

Electrical Properties

Electrical-conductor grade aluminum (EC) has an electrical conductivity of 61–63% of the electrical conductivity by volume of the International Annealed Copper Standard (IACS), which is the fourth highest electrical conductivity of the known metals and, among the nonprecious metals, is second only to copper. By weight, the electrical conductivity of aluminum is some 200% of the conductivity of copper, giving aluminum the greatest conductivity to weight ratio of any of the known metals. This means that an aluminum wire will have 61–63% of the conductance of a copper wire of the same length and cross section, but will have twice the conductance of a copper wire of the same length and weight.

The temper of EC grade aluminum has only a small effect on the conductivity, the fully hard state being only about 2% (IACS) lower in conductivity than the fully annealed state.

For equal electrical conductance and resistance, an aluminum conductor will be 1.6 times as large in cross-sectional area as a copper conductor. The diameter of the aluminum conductor, however, will be only 1.27 times as large as the copper diameter. The difference in cross-sectional areas is approximately equal to two American Wire Gauge (AWG) sizes.

This relationship makes possible a practical general rule for choosing aluminum conductors. Where the voltage drop must be similar to that of a specified size of copper conductor, an aluminum conductor two AWG sizes larger should be selected (Table 1). Because of the greater diameter and increased radiating surface, the aluminum conductor will have somewhat larger current-carrying capacity than the smaller copper conductor, and the aluminum conductor itself will weigh only half as much. With the addition of the insulating jacket, the aluminum welding cable will be at least 30% lighter than a copper welding cable two AWG sizes smaller.

Size for size, aluminum welding cable can be considered to have a current-carrying capacity of at least 78% of the current-carrying capacities listed for copper welding cables in the Insulated Power Cable Engineers Association (IPCEA) Specification S-19-81, Second Edition, February 1951, Section 7.1.1. IPCEA is presently engaged in revising and expanding the above specification, and the new specification will include a section on aluminum welding cable as well as copper. At the time of this writing, Committee 16, the Committee on Current Ratings for Aluminum Cables, is considering rating aluminum welding cable at 78 to 84% of the current rating for copper cables, with possible minor variations.

Physical Properties

Electrical-conductor grade aluminum has a specific gravity of 2.70 as compared with 8.89 for copper, and weighs 169 lb per cubic foot as against 555 lb per cubic foot for copper (Table 2). As applied to flexible welding-cable conductors, Size 2 AWG and Size 3/0 AWG aluminum welding-cable conductors weigh 64 lb per 1000 feet and 246 lb per 1000 feet respectively, compared with 162 lb per 1000 feet and 542 lb per 1000 feet, respectively, for the same size copper welding-cable conductors. With a lighter-weight conductor, the overall weight of the cable is reduced resulting in less drag on the cable when it is moved and improving the abrasion life of the jacket.

The tensile strength of semiannealed EC aluminum, which is normally used in welding cable, ranges from 15,000 to 22,000 psi and provides a conductor with adequate strength for all welding cable uses.

Table 1—Voltage Drop and Current-Carrying Capacity of Copper and Aluminum Welding Cables

Approximately equal voltage drops

	Copper		Aluminum	
Amperes*	AWG size*	Voltage drop/100 ft*	AWG size	Voltage drop/100 ft
75	6	3.58	4	3.68
100	4	3.18	2	3.07
150	3	3.70	1	3.65
200	2	3.92	1/0	3.88
250	1	3.88	2/0	3.82
300	1/0	3.72	3/0	3.63
375	2/0	3.68	4/0	3.60
450	3/0	3.51	...	...
550	4/0	3.41	...	...

Approximately equal conductor temperature

	Copper		Aluminum	
AWG size*	Amperes*	Voltage drop/100 ft*	Amperes	Voltage drop/100 ft
6	75	3.58	...	...
4	100	3.18	80	3.90
3	150	3.70	...	...
2	200	3.92	155	4.76
1	250	3.88	195	4.74
1/0	300	3.72	235	4.76
2/0	375	3.68	290	4.44
3/0	450	3.51	350	4.23
4/0	550	3.41	430	4.13

*IPCEA General Specification S-19-81, Second Edition, February 1951, Section 7.1.1. Based on 60° C conductor temperature, 40° C ambient temperature and load factors of 23 to 32%.

Table 2—Physical Properties of Semiannealed Aluminum and Annealed Copper

	EC grade aluminum		*Annealed copper*	
Specific gravity (20° C):	2.70		8.89	
Pounds per cubic foot	169		555	
Pounds per 1000 ft per circular mil	0.00891		0.003	
Specific heat, calories/g/° C	0.226		0.092	
Melting point, ° C	657		1083	
Thermal expansion, in./in./° C	23.0×10^{-6}		16.4×10^{-6}	
Tensile strength, psi	15,000	22,000	35,000	38,000
Conductivity, % IACS	61		100	
Temperature coefficient of Res/° C	0.00403		0.00393	
Relative weight for equal conductance	0.498		1.000	
Relative conductor diameter for equal conductance	1.280		1.000	
Relative cross-sectional area for equal conductance	1.639		1.000	

Table 3—Approximate Weights and Stranding of Aluminum and Copper Welding Cable

	Approx. no. of wires		*Approximate weight conductor lb/1000 ft*		*Approximate weight cable, rubber jacketed, lb/1000 ft*	
Size	*No. 30*	*No. 34*				
AWG	*AWG*	*AWG*	*Al*	*Cu*	*Al*	*Cu*
4	420	1064	40.2	136.2	99	216
2	665	1666	64.2	216.4	133	309
1	836	2107	80.8	274.2	164	388
1/0	1064	2646	102.8	342.8	195	470
2/0	1323	3325	128.5	430.1	235	585
3/0	1666	4256	161.5	542.3	278	716
4/0	2107	5320	203.7	679.4	341	887

The specific heat of aluminum is 0.226 while that of copper is 0.092. Because copper weighs 3.3 times as much as aluminum, a copper conductor will store about 35% more heat than an aluminum conductor of the same cross-sectional area. With conductors of equal resistance, however, the aluminum conductor will have a larger volume and will store about 16% more heat than the copper conductor of the same resistance. Due to this heat storage ability, the insulation on an aluminum conductor is less likely to be damaged from excessive heat during overload conditions than would a similar insulation on a copper conductor of equal resistance.

Flexibility tests performed by the Underwriters' Laboratories, Inc., on Size 12 AWG semiannealed aluminum and on Size 14 AWG annealed copper indicate that the semiannealed aluminum will stand about the same amount of repeated bending as the annealed copper. While this relationship may be true of solid conductors of the number 12 and 14 AWG size, it does not hold true for larger flexible conductors made up of many small individual strands. In laboratory tests, copper welding cables have a higher flex life than aluminum.

Laboratory flex and twist tests, at best, are inconsistent and give only a very rough indication of the flex life of the cables under test. This is particularly true of welding cables. Since both copper and aluminum welding cables have been designed for exceptional flexibility and flex life, the flex tests are made extremely abusive in order to reduce testing time to the realms of practicability. The tests cannot duplicate service conditions, nor is there any direct correlation between laboratory results and cable life in service. It is inconceivable that a welding cable could receive the destructive flexing in service that it receives in the laboratory tests.

In the past it has been found to be impractical to process aluminum strands smaller than ten mils in diameter or No. 30 AWG, and most cable manufacturers who are producing aluminum welding cable today have standardized on conductors which are made of Size 30 AWG strands. The revised IPCEA Specifications will call for No. 34 AWG (0.0063 in. diam) stranding for copper welding cable and No. 30 AWG (0.0100 in. diam) stranding for aluminum welding cables. Table 3 shows the comparative number of strands in copper and in aluminum welding cables.

The larger number of smaller strands in copper welding cable is the primary reason for the greater flex life of copper welding cables. The No. 30 AWG stranding in aluminum welding cables, however, has been found to give a good combination of flexibility, flex life and twist life, and these properties are constantly being improved through research and applied technology.

A considerable amount of work, for instance, has been done on basic cabling techniques. Copper welding-cable conductors are normally made by first bunching a number of fine-wire strands. Several bunches are then cabled or twisted into a rope with the direction of twist being opposite to that of the bunches. Several ropes are then cabled or twisted into a conductor of the proper number of strands with the final direction of twist being opposite to that of the individual ropes. While early aluminum welding-cable conductors were made by the same method, they did not prove as satisfactory as expected. After much experimenting and testing, it was found that a superior aluminum conductor could be made by first bunching a number of fine aluminum wires and then cabling or twisting concentrically the proper number of bunches with the cable twist being in the same direction as that of the bunch. This produces a conductor in which all strands are twisted in the same direction (called unilay) and in which the strands are laid essentially parallel to each other, reducing cross-overs and friction between strands and permitting the strands to move freely when the conductor is flexed or twisted. An additional advantage of this unilay conductor is a reduction in diameter because of fewer strand cross-overs which permits a smaller, lighter cable.

More recent findings indicate that, contrary to popular opinion, harder aluminum strands may extend the flex life of aluminum welding cable without visibly affecting the feel or apparent flexibility of the cable. It has been popularly accepted in the wire and cable industry that cold-work unannealed metals, being harder and more brittle, have a lower flex life than annealed

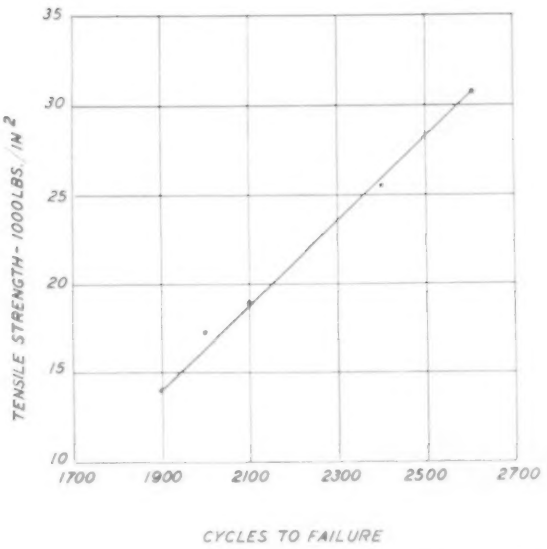


Fig. 1 Tensile strength vs. flex life. Aluminum welding cable with No. 30 AWG strands

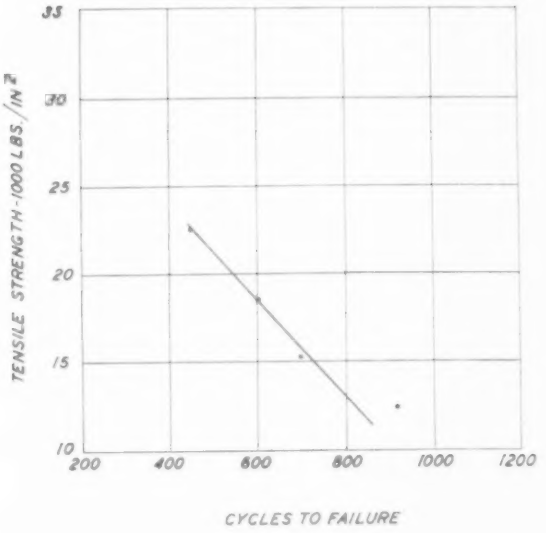


Fig. 2 Tensile strength vs. flex life. Aluminum welding cable with No. 24 AWG strands

metals, and this is readily seen in solid wire conductors. In aluminum welding-cable conductors, composed of many No. 30 AWG strands, other, as yet unexplained, factors enter the picture.

In plotting a graph for temper versus flex life (Fig. 1), it becomes apparent that for practical purposes the flex life of an aluminum welding cable composed of No. 30 AWG strands increases as the temper of the individual strands increases. On the other hand, the same size aluminum cables made of No. 24 AWG (0.0201 in.) strands, which are twice the size of No. 34 AWG strands, exhibit the characteristics normally expected when the temper of the conductor is varied. As is shown in Fig. 2, the flex life of the conductors made of No. 24 AWG decreases as the temper of the individual strands increases. The flex life of the cables with No. 24 AWG strands is also considerably less than those of the cables with No. 30 AWG strands, which is to be expected because of the increased size and reduced number of strands. There is insufficient data available at this time to attempt an explanation of the phenomena described, but investigation is being continued and there is every reason to believe that improved flex life and breaking strength of aluminum welding cables will result. It is also interesting to note that the feel or apparent flexibility of aluminum welding cables is not noticeably affected by the use of fully hard strands. Without laboratory equipment, a person cannot detect the difference between an aluminum welding cable made with fully hard strands and one made with semiannealed strands.

Smaller strand sizes for aluminum welding-cable conductors are also under active investigation. Laboratory tests on experimental welding cables made of No. 34 AWG aluminum strands show that there is a considerable increase in flex life over that obtained on cables made with No. 30 AWG aluminum strands. There are also strong indications that, with the proper combination of strand temper and cabling techniques, a welding cable made of No. 34 AWG aluminum strands may equal or closely approach the flex life of a copper welding cable.

The work being done to extend the flex life of aluminum welding cables, which has just been described, is part of an over-all and continuous program to improve the quality of aluminum cables. For all practical purposes, it is felt that the flex life that has been built into the presently available aluminum welding cables is entirely adequate for the type of service to which welding cables are subjected. Past experience indicates that there is little or no evidence of welding cables failing from flexing. The abuses to which welding cables are subjected cause the cables to fail from other reasons long before their flex life is noticeably affected. Overheating from excessive electrical currents, runovers by vehicles, burns from welding splatters and crushing and cutting between plates, girders or other sharp-edged objects are the normal causes for failure in otherwise good welding cables. Strand failures adjacent to connections and electrode holders, however, are another matter and will be discussed later.

Chemical Properties

The corrosion resistance of aluminum is excellent to nearly everything except hydrochloric, oxalic and hydrofluoric acids and strong alkalis. Corrosion resistance is of no great consequence in welding cable, however, since the cable is covered with a rubber or neoprene sheath and the exposed ends, at splices and connections, can also be covered.

Aluminum is not affected by the sulfur in rubber compounds nor does it accelerate the deterioration of rubber insulations or jackets. Copper, on the other hand accelerates the oxidation and deterioration of

rubber compounds with which it comes in contact and reacts quite readily with sulfur, resulting in a loss of flexibility and conductivity.

In the manufacture of both copper and aluminum welding cables, a paper tape is normally wrapped around the conductor to act as a separator between the conductor and the insulation or jacket. The purpose of the paper separator on aluminum welding cables is to prevent the uncured rubber compound from sinking into or penetrating the interstices between the conductor strands previous to vulcanization. If such a condition occurred, the rubber compound would cement the strands together resulting in a loss of flexibility and flex life. While the paper separator performs the same duty on copper welding cable, it also serves the additional purpose of preventing the bare copper strands from contacting the insulation and reacting with the sulfur in the insulation which would result in a mutual deterioration of both the insulation and the copper conductor. When the cable is put into service, if the paper is destroyed, as it frequently is, due to bending and flexing of the cable, there will be no damage to either an aluminum conductor or its insulation. In a copper welding cable however, when the paper tears or disintegrates in service, both the conductor and the insulation may begin to deteriorate.

Aluminum oxidizes very rapidly in air, resulting in the formation of a thin layer of oxide on its surface. The oxide coating forms in a matter of seconds, which presents both advantages and disadvantages. The thin oxide film is very tough and is resistant to many materials including oxygen and water, and therefore prevents further oxidation and increases the corrosion resistance of the aluminum. The film is an excellent electrical insulator, however, and will cause poor electrical connections unless removed or destroyed at the time the connections are made. Fortunately, the oxide film is brittle and is readily destroyed by abrasion or compression. Fiberglas brushes and steel brushes are excellent for removing the oxide, and high-pressure mechanical crimps do an excellent job of breaking up the oxide. Where practical, aluminum strands should always be brushed before applying connectors. Precautions must also be taken, such as the application of a sealing paste or oxide-inhibiting compound, to prevent the reformation of the oxide after a connection is made.

Terminating and Connecting

In terminating or connecting aluminum welding cables, any of the standard methods used with copper welding cable can be used satisfactorily with aluminum welding cable, but it should be kept in mind that aluminum is a different metal than copper and must be handled differently.

With soldered connections, noncorrosive aluminum fluxes must be used in conjunction with special aluminum solders. Special care must be taken to avoid damaging the strands when the jacket is removed from the end of the cable. The solder should be dipped in flux and inserted into the lug or connector, and the bottom of the solder socket should then be heated until the socket is about two-thirds full of molten solder. With the solder still molten, the bared conductor should be inserted slowly into the socket, allowing the flux to clean and tin the strands as they are being worked into the socket. With proper care, a soldered connection made in this manner should be electrically and mechanically good, and should give satisfactory trouble-free service. Solder connections are not recommended for applications where cables are normally overloaded to cause temperatures approaching the softening point of the solder.

Mechanical joints normally fall into one of three categories, namely, the clamp type, the screw-cone pressure type and the crimped-sleeve type. Aluminum welding cable can be locked in a clamp-type connector or holder in the same manner as copper welding cable; however, special care should be taken not to damage the strands in removing the jacket. Also, a good sealing paste compound should be used on the strands. The sealing paste compounds, of which there are many available today, usually consist of a petroleum grease base and may or may not contain a contact aid. Those containing a contact aid have finely powdered metallic particles dispersed throughout. The fine particles help to break the oxide film on the strands and reduce interstrand resistance when pressure is applied, and the grease prevents the reformation of the oxide and protects the joint from corrosion.

With the screw-cone pressure-type connector, an excellent joint can be made by observing the previously mentioned precautions, that is, by careful stripping of the jacket and by using a sealing paste on the conductor strands. In locking the cable into the connector, the rotating action of the screw-cone burnishes the aluminum strands and breaks up the oxide film, making a good low-resistance joint. The screw-cone connectors are available for splicing welding cables and also for connecting welding cables into electrode holders.

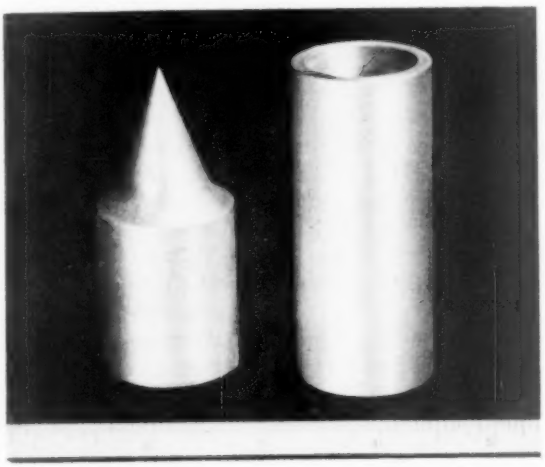
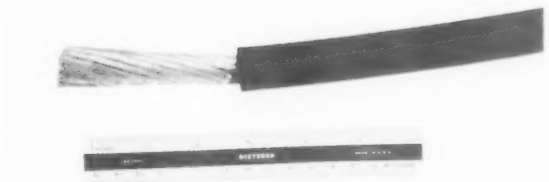
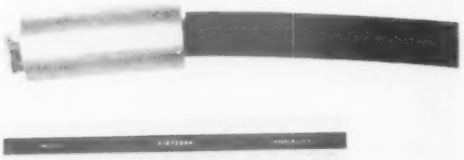


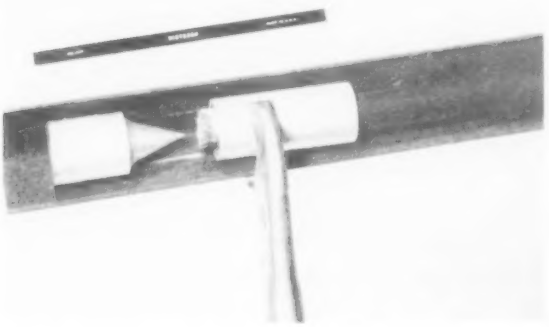
Fig. 3 Photograph of the new aluminum welding-cable connection showing the cone and sleeve ready for assembly



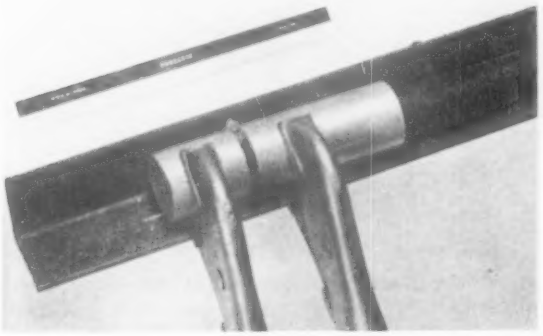
(a) Cable is stripped of insulation.



(b) Sleeve is slipped over cable.



(c) Sleeve and cable are clamped to an angle iron.



(d) Cone is tapped into place and clamped ready for tack welding.

Fig. 4 Photographs showing the assembly sequence for the aluminum welding-cable connection

Of all the popular types of welding-cable connectors now in use, the most satisfactory for aluminum welding cables is the crimped-sleeve type. Here again the jacket should be removed carefully and the exposed conductor strands coated with a sealing paste before being inserted into the sleeve. The high-pressure crimping action locks the conductor within the connector sleeve and, at the same time, burnishes the aluminum strands, breaking up the oxide film and forming an electrically and mechanically good joint.

In addition to the familiar accessories for copper welding cables, which have just been discussed, there is an increasing number of accessories on the market today which are designed primarily for use with aluminum cables or with either aluminum or copper cables. Some manufacturers are now making electrode holders of aluminum which not only have the advantage of lighter weight, but which also make more efficient and longer lasting connections to aluminum welding cables. There are also lugs and connectors available made either of aluminum or an aluminum sleeve welded to a copper or brass body. These greatly facilitate the connecting and terminating of aluminum welding cables, and will give better performance than accessories made of copper.

Because of the difference in the rates of thermal expansion of copper and aluminum, an aluminum to copper connection may exhibit signs of thermal ratcheting if exposed to severe heating caused by high overload currents. When subjected to heat, the aluminum conductor expands more rapidly than the copper connector, causing an increase in pressure on the conductor. When the elastic limit of the aluminum is exceeded a plastic or cold flow takes place in the aluminum, reducing the pressure. When cooled, the aluminum cross section is smaller than it was originally, causing a looser, higher-resistance connection. Repeated cycling of this nature results in increasing resistance and heat until the joint finally burns off.

While this thermal ratcheting may take place when an aluminum cable is terminated in a copper-bodied connector that is subjected to frequent or periodical high, heat-producing overload currents, there is little difficulty observed when an aluminum conductor is used of a size sufficient to carry the expected currents without exceeding its temperature rating. When aluminum-bodied connectors or terminations are used on aluminum cables, there is no problem of thermal ratcheting since both the conductor and the connector have the same rate of thermal expansion. It is therefore recommended that aluminum connectors and terminations be used on aluminum welding cables for best performance, and in the case of high current and high heat it becomes a necessity to use aluminum fittings on aluminum cables.

One of the most recent advances in the connecting of aluminum welding cables has been the development of a reusable welded joint. Welded joints in aluminum cable have long been known to give better performance than soldered or mechanical joints, particularly under

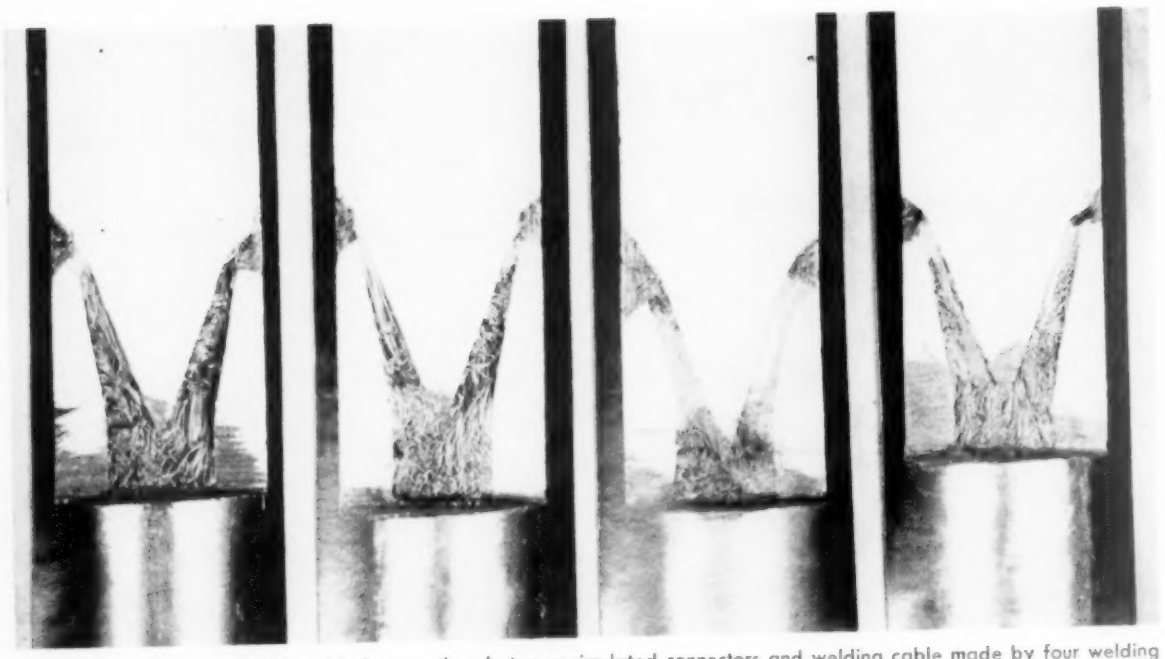


Fig. 5 Cross sections through welded connections between simulated connectors and welding cable made by four welding processes

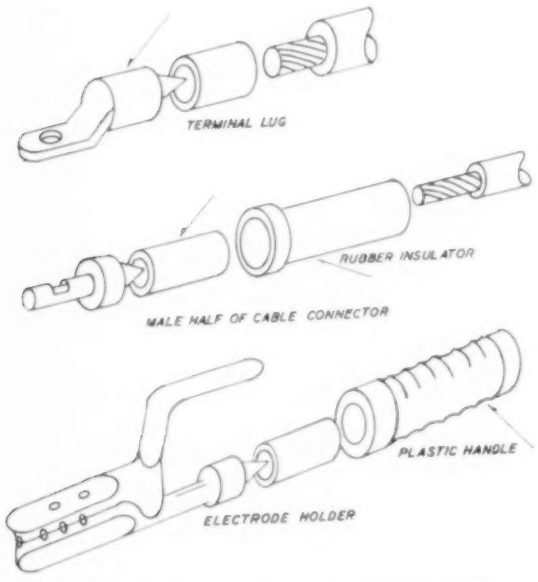


Fig. 6 Sketches illustrating use of aluminum cable connection with standard welding-cable lugs, connectors and electrode holders

conditions of high currents and high heat. In the past, however, welded joints have been difficult to make, requiring shielded welding equipment and a high degree of skill. The new joint can be easily made using any of the more common welding processes, and can be readily adapted to lugs and holders as well as connectors.

The parts that make up the new joint (Fig. 3) consist of an aluminum sleeve and a short length of solid aluminum rod of the same diameter with a cone-shaped taper on one end. In making the joint (Fig. 4), the bared end of the aluminum welding cable is inserted into the sleeve, and the sleeve is clamped to an angle iron. The cone is inserted into the center of the wire, tapped firmly into the sleeve section and clamped in place. The joint is then welded by the inert-gas tungsten-arc, inert-gas metal-arc, oxyacetylene or shielded-arc welding processes, any of which will produce satisfactory welds (Fig. 5). By using a pure-aluminum filler metal, the electrical resistance of the joint is kept to a minimum.

To reuse the connection, it is only necessary to cut through the weld with a hacksaw, taking care not to cut through the cone. The joint is then easily separated and any conductor strands which may adhere are easily removed by filing or grinding before reusing.

For practical use, the cone section can be mounted on, or made a part of, an electrode holder, lug or connector (Figs. 6 and 7). It is expected that joints of this type will be available commercially in the very near future.*

Also available on the market today are devices designed to reduce failures caused by excessive bending, pulling and twisting at the electrode holder or at connections. Failures of this type are common with both aluminum and copper welding cables, and are not true cable-flex failures. These failures occur in the small section of bare conductor between the end of the cable jacket and the physical connection. While a good welding cable is designed so that with the jacket in place the strains of tension, twisting and flexing are

* The joint structure and method of making same described herein are protected by patent rights of Kaiser Aluminum & Chemical Corp.

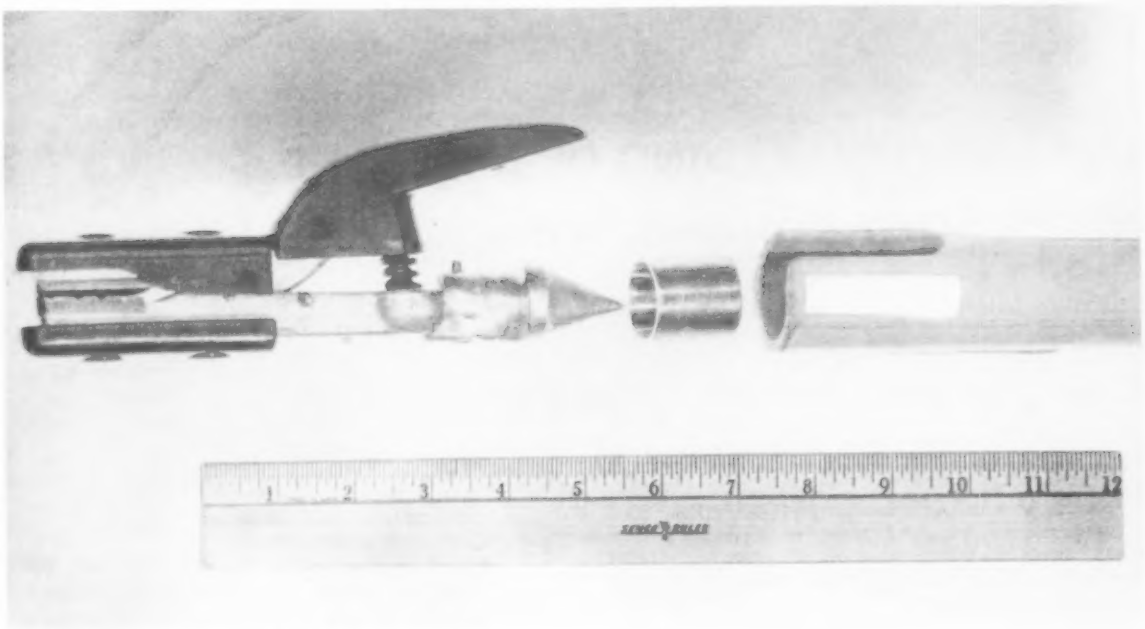


Fig. 7 Electrode holder with cone section attached

more or less evenly distributed among the individual strands that make up the conductor, the removal of the jacket and the clamping of the conductor in a connector changes the balanced relationship between the strands. The connections not only must be good electrically but also mechanically since the cable weight is supported by the connection. Instead of being distributed among all the strands, the strains due to weight, flexing and twisting are frequently concentrated on only a relatively few strands in the bared portion of the conductor. When the strains exceed the endurance limit of the strands, they start breaking, a few at a time, reducing the cross-sectional area of the conductor and causing the connection to heat up. This is a progressive process, and as the strand breakage increases, the conductor becomes weaker and smaller in current-carrying capacity until finally the conductor breaks off completely or overheats and destroys the connection.

The devices designed to alleviate this condition are of two general types. One type consists of a rubber or neoprene sleeve which slides over the connection and extends over the jacketed section of the cable with a snug fit. The sleeve may or may not be molded to the jacket and the connector, although molding will give not only better protection to the strands but will also give better protection against moisture. In addition to giving protection to the connection itself, the additional thickness of rubber over the cable jacket adjacent to the connector stiffens the cable at this point, increasing the bending radius and reducing the strain on the individual strands at the connection.

The other type consists of a metal saddle which acts as a support for the bare strands. One end is inserted into the clamp or socket of the holder or connector along with the bared conductor, while the other end is crimped around the jacket of the cable adjacent to the connection. This immobilizes the section of cable in contact with the saddle, causing any bending or twisting to take place on the jacketed cable and relieving the strain on the individual strands of the short section of exposed conductor between the connection and the jacket. This device should do much to extend the mechanical life of a welding-cable connection.

Summary

Aluminum welding cable offers many advantages to its users. A steadily increasing capacity for producing the base metal insures a greater availability and a lower cost. The light weight of aluminum welding cable facilitates handling and transporting, and reduces abrasion and abuses of the jacket caused by dragging the cable. The good flexibility and light weight also improves efficiency and reduces operator fatigue.

With proper care, aluminum welding cable can be connected by any of the methods which are standard in the welding industry today. The high-pressure crimped sleeve connection is considered to be the best available for aluminum cable; however, a new welded joint connection is expected to be available shortly which will give superior performance. The use of accessories, such as lugs, connectors and electrode holders which have been designed for use with aluminum welding cable will do much toward improving the operation.

Because of the consistently low price and the great abundance of aluminum, increasing amounts of aluminum welding cable are being used and all indications are that much larger amounts will be used in the future.

AUTOMATIC WELDING OF AIRCRAFT ACCESSORY TURBINE WHEELS

Faster welding speeds, higher deposition rates and reduction in amount of rework necessary to maintain high quality are among the advantages outlined for automatic welding of turbine wheels

BY A. J. ROSENBERG AND E. W. JAMISON

INTRODUCTION. One of the most critical products in industry today is the high-speed turbine wheel. This is particularly true in the Aircraft Accessory Turbine Department of General Electric Co. where reliability must be coupled with low manufacturing costs. Welding plays an important part in the fabrication of such wheels, since it permits the combination of a variety of materials for optimum properties in the wheel blank, shaft and buckets. For example, a low-alloy-steel forged hub and shaft are welded to a cast high-temperature alloy bucket in the wheel under discussion in this paper.

Since an average welding operator can normally weld only three or four inches of groove a minute, while travel speeds of 50 to 75 ipm are not uncommon in automatic welding, it is apparent that economies can be made by going to automatic welding on the basis of speed alone. In addition, deposition rates are significantly higher for automatic techniques so that approximately half the number of weld passes are required to complete a wheel. Equally important is the reduction in the amount of rework necessary to maintain a high-quality standard in units to be shipped. It is in this area that automatic welding can offer marked improvement.

In manual-welded wheels, the metal-arc process is used. In this case, a coated wire is employed in which the chemical compounds in the coating break down during welding and form a gaseous and slag shielding for the solidifying weld metal. Occasionally, the slag becomes entrapped during solidification, or is not completely removed by the operator before depositing additional weld metal. In any case, it must be chipped and brushed after every few inches of welding, and adds materially to the cost of the job. The problem of covered electrodes and slag is eliminated in inert-gas-shielded metal-arc welding, in which a bare wire is fed automatically to the joint being welded. The molten weld area is protected by an atmosphere of inert gas.

Equipment and Material

Several manufacturers produce competitive equipment for this process, differing in the methods of controls or type of power source. Equipment with rising volt-ampere characteristics was selected for the developments discussed in this report.

Materials employed in the design consist of a cast cobalt-base high-temperature alloy bucket and a low-alloy forged and heat-treated AISI 4340 steel hub. Selection of filler material was based on the strength requirements of the wheel, as well as its welding characteristics. Type 19-9 WMo (Type 349) had been successfully applied as a manual electrode on earlier designs, so that this material in spooled form was employed throughout this study.

Weld Cracking

Radial Cracking

Joining of individual buckets to a turbine-wheel hub is an inherently difficult problem regardless of the welding method used because of cracking. The joint configuration itself resembles a crack-sensitivity test developed at the Naval Research Laboratory to evaluate the welding characteristics of materials. In this test, strips of materials being tested are fixtured side by side and a continuous weld is made across the separations. Except for rare instances, cracks emanate from the strip separations and extend into the weld metal. As might be expected, the same condition exists in welding buckets to wheels (see Fig. 1). Cracks emanate from the bucket

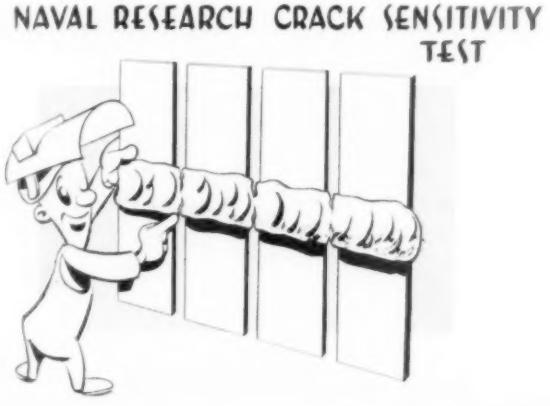


Fig. 1 Naval Research Laboratory crack-sensitivity test used to evaluate welding characteristics of materials

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Paper to be presented at the 1958 AWS Annual Spring Meeting to be held in St. Louis, Mo., April 14th to 18th.

separation and extend into the weld, aggravated by the circumferential stresses induced in welding a complete circle.

The mechanism by which this "radial" cracking occurs can be explained in terms of the solidification pattern of the weld. Molten weld metal solidifies from the joint walls inward to the center and at right angles to the joint walls (see Fig. 2). At the bucket separation, there is no cold wall to initiate the chilling of the molten weld and, therefore, this area is the last to solidify and the liquid film present there cannot support the contractual weld stresses and cracks. In addition, low-melting phases and foreign materials precipitate in these areas and further contribute toward cracking.

Radial cracking is further aggravated by automatic welding because the rapid solidification of the molten weld metal tends to increase the contractual stress levels over those encountered in manual welding. Limits for acceptable radial cracking must be established for each turbine-wheel application, depending upon the service conditions to which they are subjected.

Fusion-Line Cracking

A more serious type of cracking commonly encountered is referred to as fusion-line or circumferential cracking. This type of defect extends in a circumferential direction around the wheel, between the bucket material and the weld. It is associated with the specific composition of the bucket alloy, and is quite pronounced in the material employed in this study.

Chrome-moly carbides present in little islands in the matrix of this alloy contribute to its high-temperature strength. Normal structure appears in Fig. 3. During welding, these carbides go into solution and precipitate out in a continuous chain during solidification and cooling, after welding (Fig. 4). This same phase is present if welded with or without preheat, and would occur on heating and cooling without welding, although they would be well dispersed.

This chain of carbides contributes to circumferential cracking since it possesses a relatively low melting point and is the last area to solidify. Thus, if it is subjected to high weld-shrinkage stresses while still in a liquid-film state, cracking occurs in a manner similar to other "hot short" materials.

The extension of circumferential cracking can result in bucket failures in service and, therefore, must be closely controlled. While limits depend on the particular application, no circumferential cracking was permissible on this particular wheel.

A marked decrease in circumferential cracking when automatically welding is brought about because the time at elevated temperatures is reduced to the extent that solution of carbides is minimized. Further, those carbides which do go into solution are prevented from segregating into chains because of the rapid solidification and cooling rate.

Transformation Cracking

Another type of cracking common in welded turbine wheels is that associated with the hub material. In this case, the hub is AISI 4340 alloy steel, containing 0.40% carbon. This material hardens when quenched from temperatures above 1300° F because of an allotropic change. If the cooling is slow, approaching equilibrium conditions, then the resulting structure is soft and ductile. When the cooling is rapid, such as that

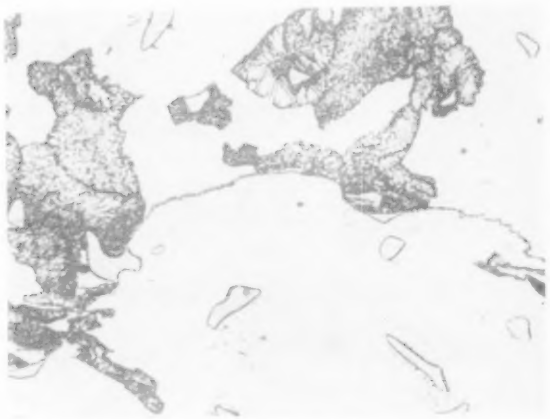


Fig. 3 Normal structure of the bucket material

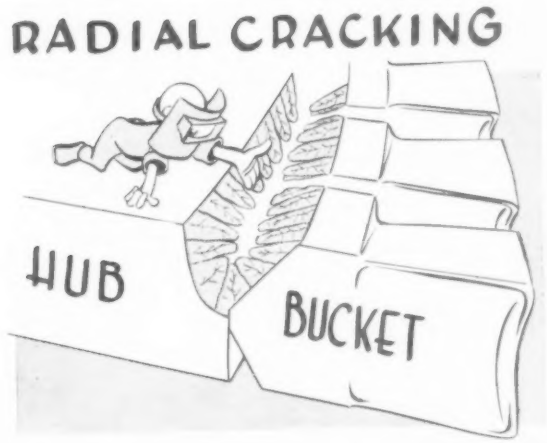


Fig. 2 Radial cracks emanate from the bucket separations

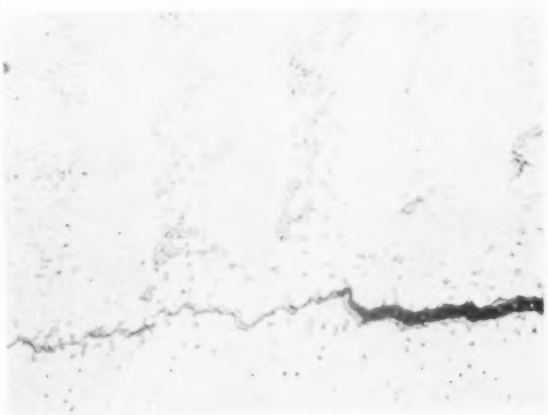


Fig. 4 Crack in the precipitated-carbide phase at the weld interface

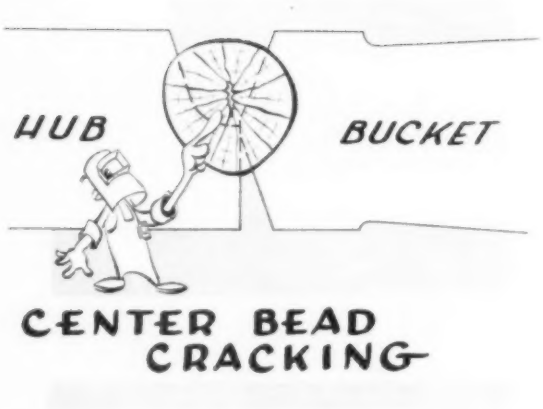


Fig. 5 Center-bead cracking

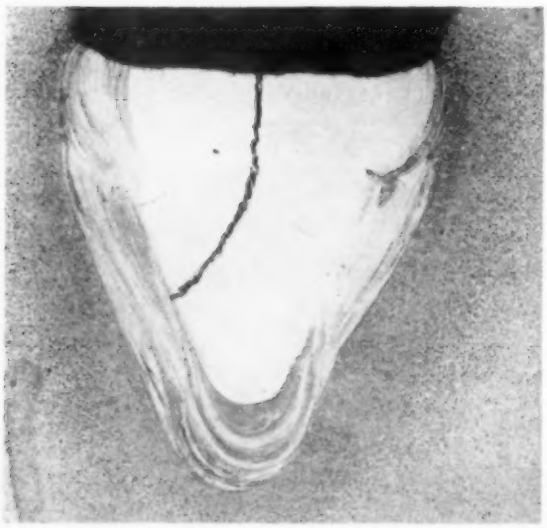


Fig. 6 Center-bead cracking in deep and narrow penetrating welds. Shielding gas: 99% Argon – 1% Oxygen

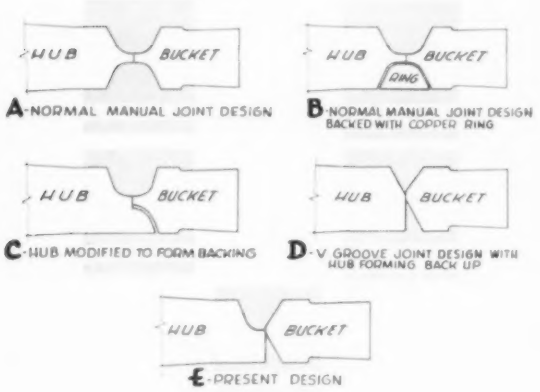


Fig. 7 Joint designs evaluated for automatic welding

following welding, the structure is martensitic and highly stressed, hard and brittle. In combination with residual weld stresses, brittle fracture may result. Preheating slows down the cooling rate, prevents the martensite transformation, and eliminates cracking. It is for this reason that preheating was employed throughout this investigation. It does not alleviate radial or circumferential cracking. Postheating is employed to transform isothermally the austenite to a lower stressed bainitic structure. The final assembly is later fully stress annealed to minimize residual welding stresses and transform the bainitic structure.

Center-Bead Cracking

A type of cracking associated with the weld metal and known as "center-bead" cracking may also be present in welded-groove designs. This cracking is associated with the weld configuration and solidification pattern (Fig. 5). Metal solidifies from the joint walls inward toward the center. If the center of the weld is in a liquid-film state at the same time contractual stresses are present, cracking may occur. A narrow, deep weld is particularly susceptible to this type of cracking, as shown in Fig. 6, but the use of proper joint designs and welding-pass sequence can eliminate the difficulty. Since center-bead cracks progress in a circumferential manner, none are permissible.

Special emphasis was given in minimizing or eliminating these cracking difficulties when establishing joint-groove designs and welding procedures.

Evolution of Satisfactory Procedure

Most of the experimental development welding was carried out with grooved plates of cold-rolled steel simulating wheel configurations, with the exception of the bucket separations. Occasional wheels were welded

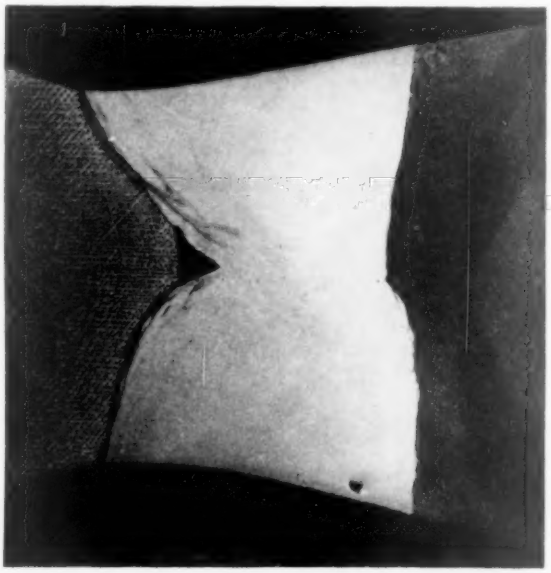


Fig. 8 Lack of penetration at the center of the weld on the original development wheel

to verify results. A joint suitable for manual welding (double U) proved unsatisfactory for automatic welding because the increased penetration resulted in burn-through (see Fig. 7). Copper backing of the underside did not alleviate the situation and, in fact, was detrimental because of fusion of the copper backing ring by the filler material.

Backing of joint with a shoulder on the hub material which mates with the contour of the bucket base solved the penetration problem by acting as a heat sink. However, the narrow bucket base burned away and permitted damage to the bucket air-foil section. The bucket was therefore redesigned with a V-preparation to provide a wider bucket base.

When the redesigned bucket was used in conjunction with a single-V-groove on the hub, backing by the hub material, center-bead cracking was observed when welding with a single pass and the groove was too narrow for multiple passes.

Consequently, the hub was machined to a single-J groove, self backing. After depositing one pass on the groove side, the backing was machined out to the center of the wheel to insure complete penetration and a concentric groove for the second side. If the second side is not machined to center, lack of penetration may result, as shown in Fig. 8.

In early developments, difficulty was experienced with voids at the weld overlap (start and stops) as illustrated in Fig. 9. By employing a "running start" in which the wheel was rotating when the arc was initiated, and by proper adjustment in starting wire feed, this problem was eliminated. Two passes per side were sufficient in the original development wheel design and a satisfactory procedure was established, using $\frac{1}{16}$-in. diam filler wire. However, redesign of the wheel (Fig. 10) to permit operation at a higher stress level and the addition of material for balancing, increased the thickness in the weld area greatly.

The two-pass-per-side procedure failed to fill the groove completely in the thicker wheel; slowing down the travel speed to permit greater deposition of material filled the groove satisfactorily but resulted in center-bead cracking because of the configuration. Three weld passes per side was impractical with the $\frac{1}{16}$-in. diam welding wire. The current had to be reduced to the extent that the metal-transfer characteristics of the molten weld wire changed from a desired fine spray-like transfer to an undesirable globular transfer. The spray transfer enhances arc stability and uniformity of arcing, while erratic arcing with occasional shorting can be expected with the globular type.

In order to maintain the proper current density and yet deposit a smaller weld, it was necessary to reduce the wire diameter to 0.045 in. The groove design was unaltered from that already developed.

The three-pass-per-side welding procedure (Fig. 11) employing 0.045-in. wire, appeared satisfactory. Settings for wire feed were converted from those developed

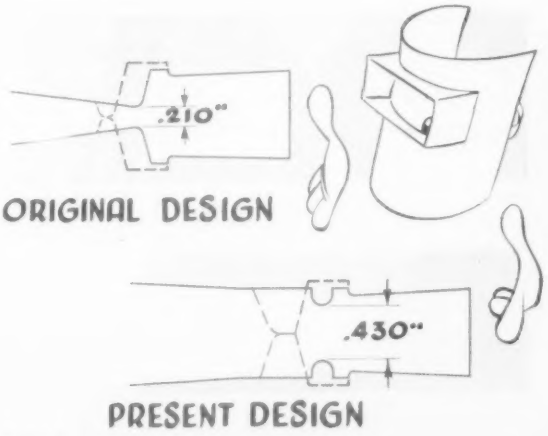


Fig. 10 Original and redesigned wheel

Fig. 9 Void at the start of a weld due to improper starting wire feed

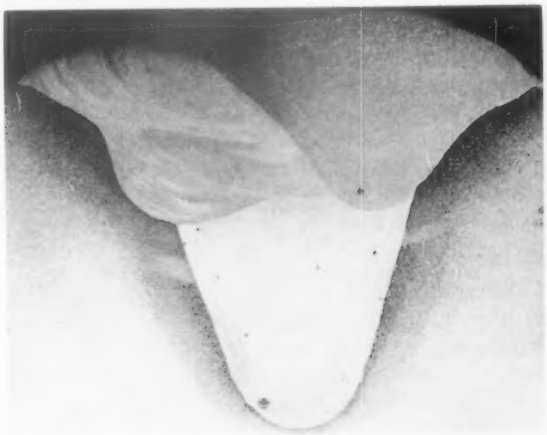


Fig. 11 Present weld configuration developed in grooved plates

with the 0.062-in. wire on the basis of maintaining the same current density.

Porosity

Procedures developed thus far produced wheels which possessed satisfactory starts, were free of circumferential or center-bead cracking, and in which radial cracking was within the limits set. Throughout the investigation, however, considerable porosity had been observed in the weld. Porosity is caused by the entrapment of gas, and is present to at least a minor extent in all welding. In the case of automatic welding of wheels, increased amounts of porosity were encountered since the travel speeds and solidification rates of this type of welding are such that gases do not have time to escape.

A study was made of the factors affecting porosity in automatic welding, as part of the over-all welded-wheel program. One type of severe porosity was encountered in the first few inches of welding, but not on every specimen. This was traced to the introduction of water vapor in the inert-gas stream because of condensation in the water-cooled nozzle during preheating with a gas torch, or on humid days. Utilization of a solenoid to restrict cooling water flow to welding periods only, overcame this difficulty.

Scattered porosity throughout the weld apparent in Fig. 12 could be reduced appreciably by increasing the inert-gas flow during welding. However, excessive flow proved detrimental because of a siphoning effect, which introduced air. For this application, 70 CFH of 1% oxygen-argon was most satisfactory.

A suggestion to use CO_2 additions to the argon-oxygen mixture was made because of the recent successes in reducing porosity in mild-steel welds with carbon-dioxide shielding. Carbon dioxide, however, results in a deep-penetrating weld configuration which is susceptible to center-bead cracking. In several attempts to introduce small amounts of CO_2 in the shielding-gas stream, it was observed that porosity was markedly reduced and arc stability was improved, but center-bead cracking, shown in Fig. 13, was observed and an increased hardness in the weld area was noted. The use of CO_2 was not pursued to any greater extent because of the general urgency of the program. This may be a worth-while subject for future study.

One of the major factors contributing to general porosity was surface contamination of the welding wire. Pickling of the wire in a 10% solution of nitric-hydrofluoric acids, or vacuum annealing, to remove surface contaminators such as oxides or drawing-compound residues, reduced porosity to acceptable amounts.

Welding Wire

A great deal of trouble was encountered in obtaining satisfactory welding wire for automatic operation. Shipments of wire that were received possessed satisfactory mechanical features such as smoothness, temper cast, twist, etc., but could not be used because of extremely poor arc stability.

A comparison was made between satisfactory and unsatisfactory wire on the basis of chemistry, hardness,

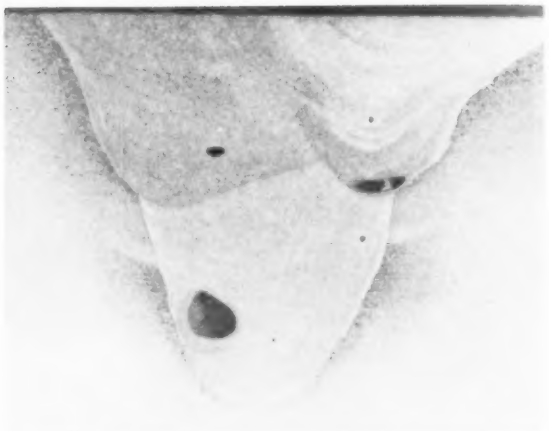


Fig. 12 Example of porosity due to improper flow of shielding gas

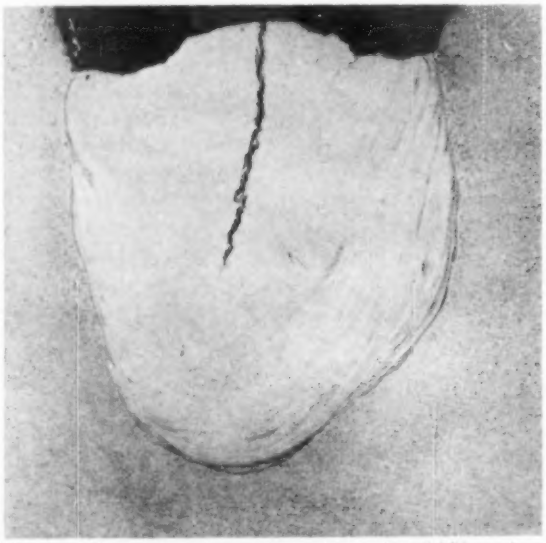


Fig. 13 Center-bead cracking when using 10% carbon dioxide in conjunction with the normal argon-oxygen shielding gas

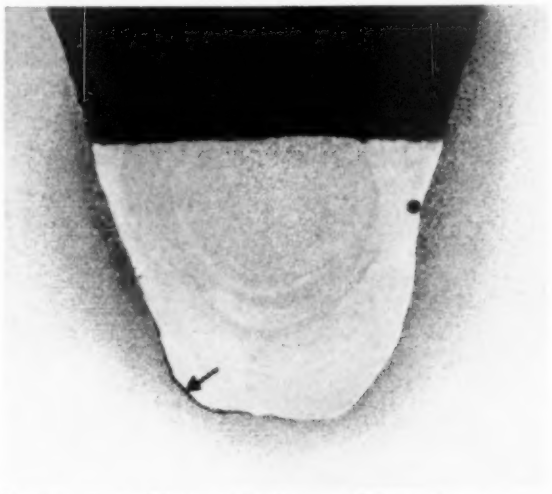


Fig. 14 Lack of fusion at the bottom of the root pass

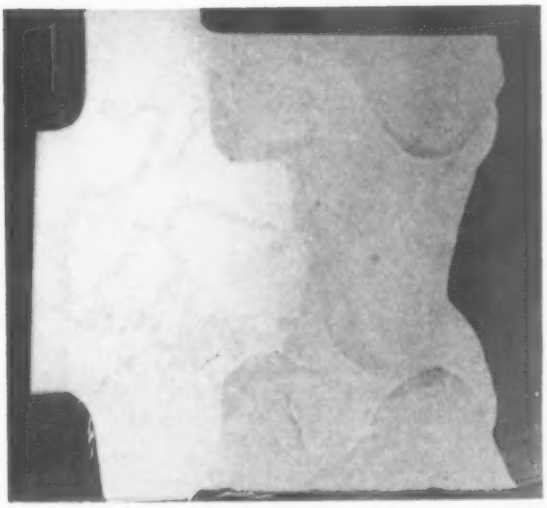


Fig. 15 Center-bead cracking can occur on any pass if deep-penetrating welds are obtained.

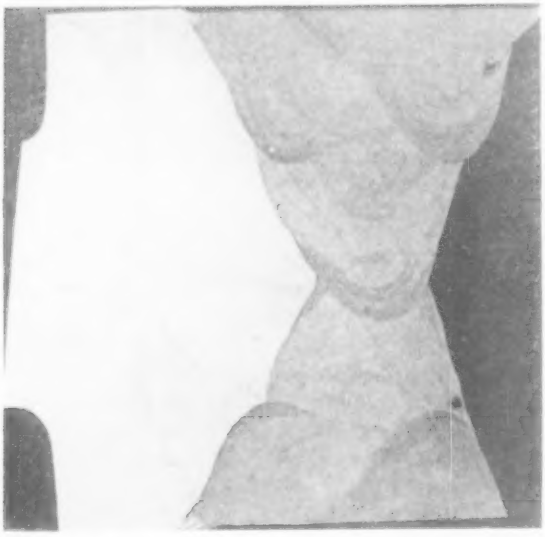


Fig. 16 Normal weld configuration for production wheels

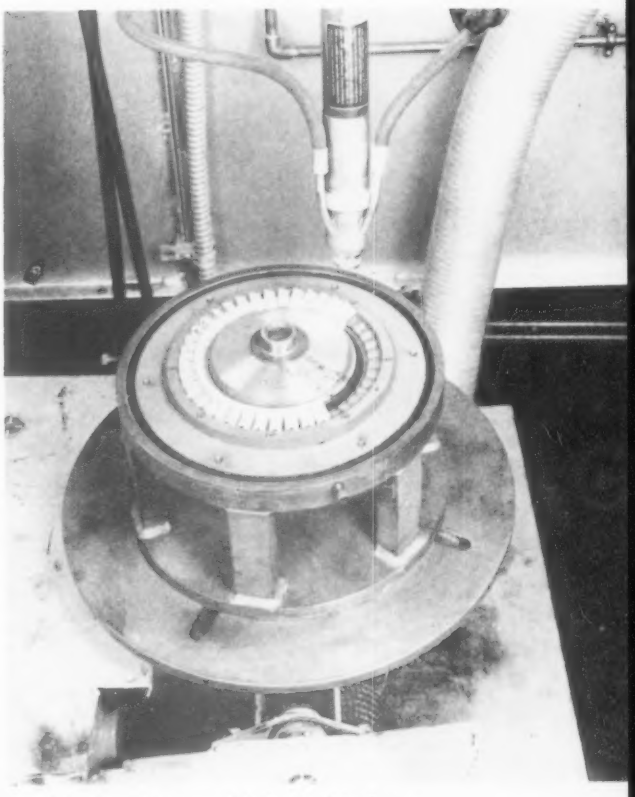


Fig. 17 Partially-assembled wheel in fixture

tensile properties, X-ray diffraction and surface resistance. The major difference was in the latter property, where the poorer wire exhibited a large variation in surface resistance which may have been caused by incomplete removal of surface oxides in combination with imbedding of drawing compounds.

Other shipments of wire from additional suppliers were so poorly spooled that the cast and twist caused helical feeding in the nozzle and were unsuitable for use. Some was returned and respooled, but deep pits and oxide inclusions caused erratic feeding and arcing, and the wire was therefore rejected. Still other wires possessed kinks, lumps, low areas and scored portions, surface oxides and improper cast and were generally unfit for use in automatic welding.

Sizing of this wire by suppliers failed to remove the surface oxides, kinks and low and scored areas. Satisfactory wire was ultimately received only when the producers became aware and agreed to the need for high-level wire quality for fully automatic welding.

During these investigations samples of one wire were vacuum annealed at 800° F for 20 min and vacuum cooled in an effort to correct the twist, as well as remove surface contaminators. Wire thus treated subsequently proved to be the best employed in the Laboratory for welding wheels. In addition to feeding extremely smoothly and consistently, the excellent surface finish produced welds of relatively low porosity content.

Vacuum annealing or bright annealing in processing wire is thus an extremely important factor in obtaining satisfactory surface finishes for automatic welding. This can be further pursued, if necessary.

Because of the variations in surface finish and surface resistance, the voltage drop in the welding nozzle can vary from one heat of wire to the next, even with completely satisfactory wire. This voltage drop may be sufficient to cause a decrease in the amount of weld penetration into the root of the groove or against the side walls, even though the surface appearance of the weld is excellent and it appears that satisfactory metal transfer is being obtained (Fig. 14). On the other hand, a too-high voltage will result in deep penetrating welds and cracking can be expected in any pass as shown in Fig. 15. Therefore, it is our practice to deposit a sample

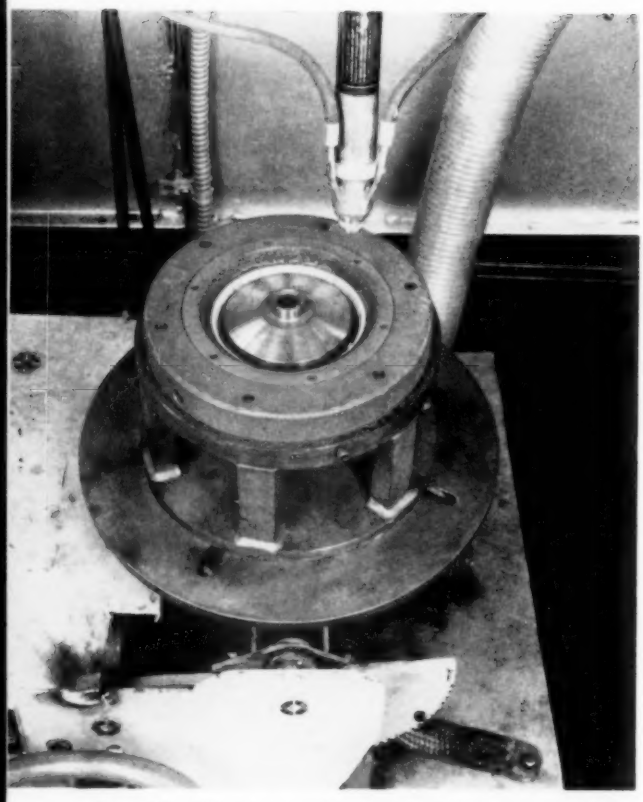


Fig. 18 Wheel assembled with fixture cover holding buckets in place

Fig. 19 Automatic welding of assembled turbine wheel

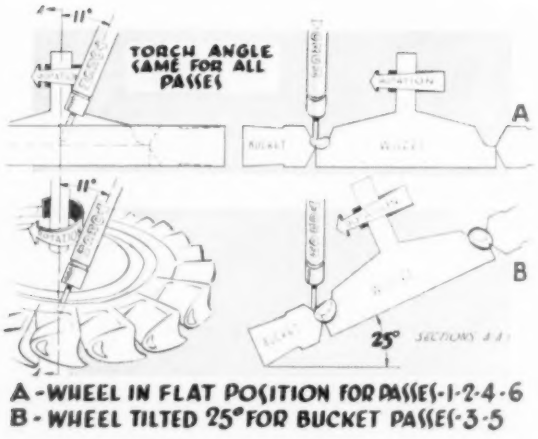


Fig. 20 Torch angle and position of wheel during welding

weld in a grooved plate in order to establish the voltage necessary for good penetration for different lots of wire employed. Figure 16 shows normal penetration required in production.

Welding Procedure

In initially setting up to weld a wheel automatically, the individual buckets are fixtured against the hub and held in proper alignment by locating from the foil section of each bucket, as shown in Figs. 17, 18 and 19.

Once fixtured, the entire assembly is preheated at 550 to 700° F, in order to retard the cooling rate after welding and thus prevent cracking of the hub material. For the same reason, a postheat after welding at the same temperature for 1 hr is necessary.

Torch angle and nozzle height are extremely important in order to obtain uniform gas coverage and weld location and configuration. The torch is centered vertically above the groove, at an 11-deg forehand angle (see Fig. 20). The root passes on each side of the wheel are deposited with the wheel in a horizontal plane. The bucket passes are welded with the wheel positioned at a 25-deg angle in order to locate this weld bead properly.

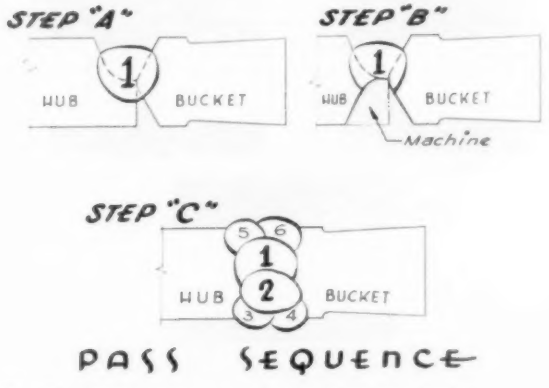


Fig. 21 Pass sequence used on production wheel

Fig. 22 Lack of fusion between two top passes

with the torch angle unchanged, and welding still carried out in the forehand direction.

The final hub passes on each side are done in the same manner as the root beads. Weld sequence consists of depositing the root pass on the stub side of the hub (see Fig. 21). The shaft side is then machined to remove the metal used for backing and to generate preparation for second pass. This shaft-side root pass is then deposited, followed by the bucket and hub pass on the same side. The bucket distorts toward the first pass, and the three subsequent passes on the opposite side compensate for this movement. The final two passes on the hub side are then deposited, leaving very little bucket run-out. Proper clearances in the fixture are necessary to permit this movement, thereby preventing cracking and yet controlling bucket alignment.

The nozzle height affects the voltage drop in the wire extending from the contact tip to the work. For repetitive results, a consistent nozzle height is necessary, although the actual value is relatively unimportant.

A travel speed of 26 sec per revolution is employed for the root and hub passes, while 18 sec per revolution is used for the bucket pass in order to deposit a small weld and leave sufficient area for the final hub pass. When too large a bucket weld is deposited, lack of penetration can result (Fig. 22).

It is extremely important that the surfaces of the root passes be as uniform as possible in order to deposit the remaining welds properly. Typical root pass is shown in Fig. 23. If the surfaces of these root-pass welds are excessively reinforced, or if skips exist between the weld and the groove side-walls, it is not possible to obtain complete weld penetration in later passes. Should

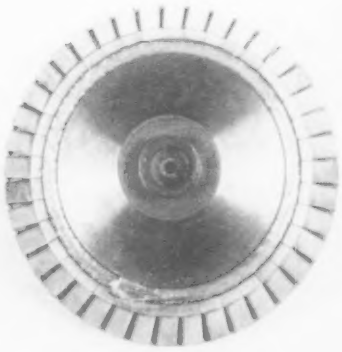


Fig. 23 Typical root pass

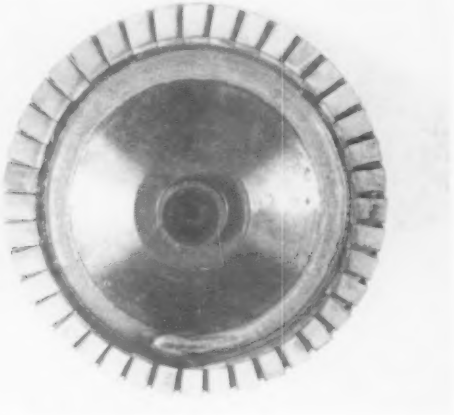


Fig. 24 Completed production wheel

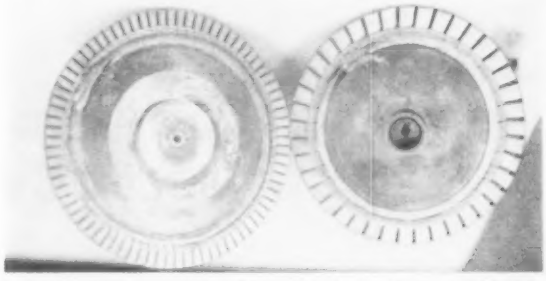
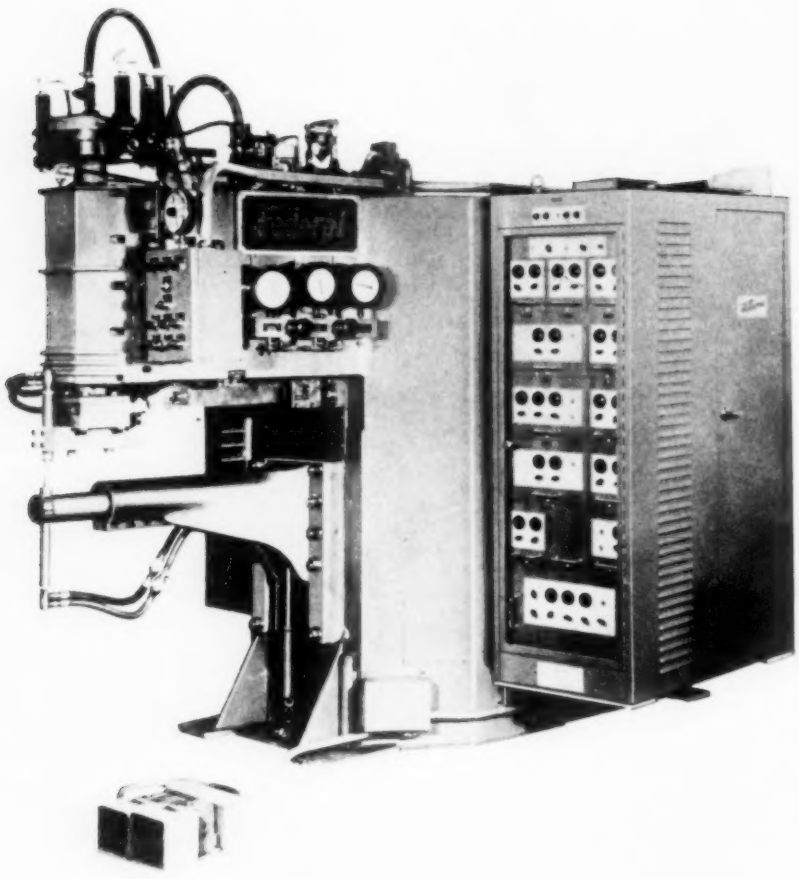


Fig. 25 Two types of turbine wheels now being welded in production

either of these conditions occur, the entire root pass should be removed and rewelded with an adjusted setting. If the wheels are concentrically aligned prior to welding, no manual guidance or adjustments are necessary during the welding cycle.

Since the initial development of procedures, automatic welding has been applied to other wheels on a developmental basis. Figure 24 shows the wheel requiring three passes per side—total arcing time, less than three minutes. Figure 25 shows the same wheel as in Fig. 24 and a second wheel which is narrower and requires only one pass per side. The weld time is less than one minute.



Counter-tube control as used with aircraft spot-welding machine

FREQUENCY-CONVERTER WELDING CONTROL USING COUNTING TUBES

Paper describes how the development of counting tubes and other engineering improvements have been applied to simplify frequency-converter welding controls and make them easier to maintain

BY L. R. BRONIAK AND W. A. CHAISSON

INTRODUCTION. Three-phase frequency-converter controls have been difficult to set up and maintain in service because of the complex circuitry required to perform the welding functions desired. The purpose of this paper is to describe how the development of counting tubes and other engineering improvements were applied to simplify the welding controls and make them easier to maintain.

L. R. Broniak and **W. A. Chaisson** are associated with the Weltronic Co., Detroit, Mich.

Paper to be presented at 1958 AWS Annual Spring Meeting to be held in St. Louis, Mo., April 14th to 18th.

Process Patent pending.

Early Model Controls

Figure 1 shows a three-phase control, which was used by resistance-welding fabricators prior to the advent of counter tubes. The photo illustrates the complexity of the control. The service engineer would experience some consternation if told it was his job to locate the

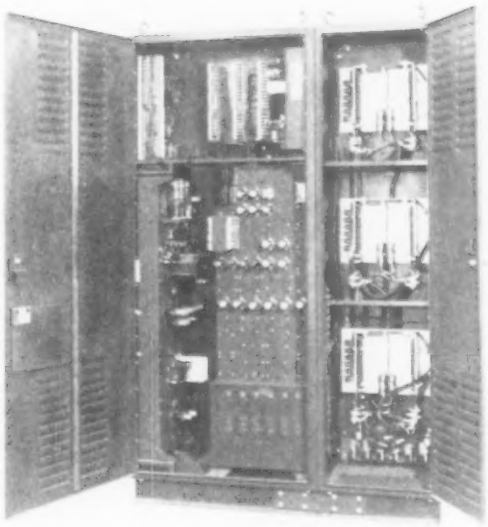


Fig. 1 Old style frequency-converter control

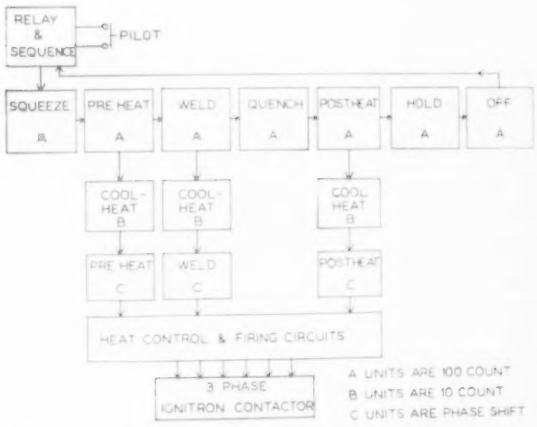


Fig. 2 Diagram illustrating building-block method of control

trouble somewhere in that maze of wiring. All of the functions of the control are interwoven into one complex piece of circuitry. It is small wonder that even the most ardent supporters of frequency-converter type controls were willing to admit that the complexity of this type of control was not conducive to rapid repair on the firing line, hence resulting in less than optimum production.

Three Stumbling Blocks to Maintenance

Several reasons contributed to why maintenance has always been a major project on three-phase frequency-converter controls. One of the most important is the fact that the whole control package has been always designed and serviced as one large complete unit. With prolonged experience, it was possible to locate the difficulty by gradual elimination of a multitude of possible causes of trouble. All resistance-welding controls, prior to the use of counter-tube circuits, utilized resistors and capacitors to obtain timing circuits. The quality control of these components is such that when they are used in an electronic circuit, the satisfactory operating range of the circuit is rather narrow. Even though the proper values of resistors and capacitors are designed into a circuit, these values change with age and operating conditions. A change in temperature or aging of the component causes a change in value of that component, resulting in a corresponding change in timing. This condition of instability of components makes it exceedingly difficult for a service engineer to analyze welding-control difficulties.

Since frequency-converter welders are normally used on resistance-welding applications which require great accuracy, it is of the utmost importance that there be a proper balance between the positive and negative pulses of current obtained by use of the phase-shift heat control. Unbalance causes erratic operation of the welding transformer, resulting in improper welds.

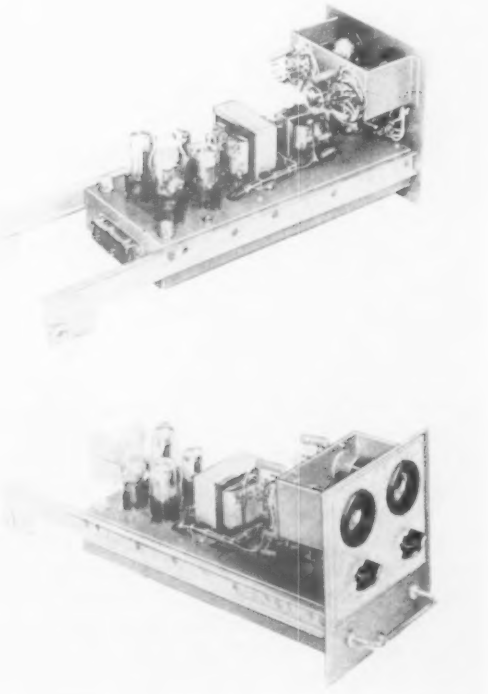


Fig. 3 100 count chassis

New Ideas in Control Design

To eliminate the complexity of circuitry, it was decided to make up the entire control from unitized, identical building blocks. Figure 2 shows a block diagram of the building blocks as put together in a basic three-phase frequency welder control. You will note that the functions of Squeeze, Preheat, Weld, Quench, Postheat, Hold and Off, which are designated as "A" type units, are all identical and interchangeable. The "A"

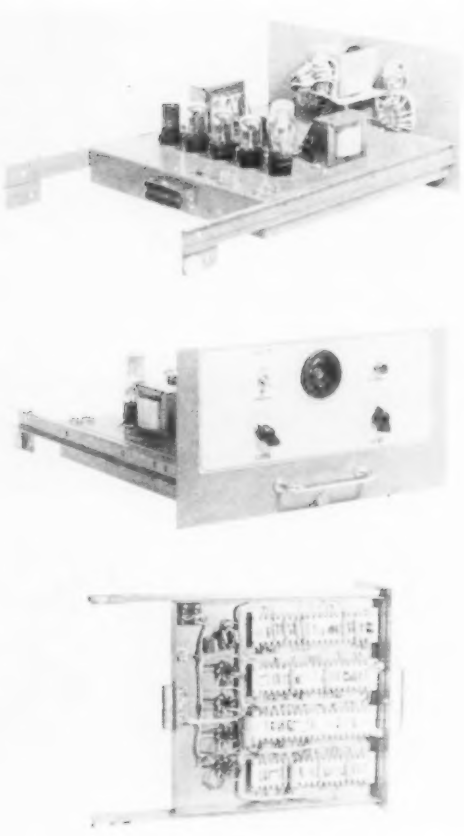


Fig. 4 Heat, cool, current-decay chassis

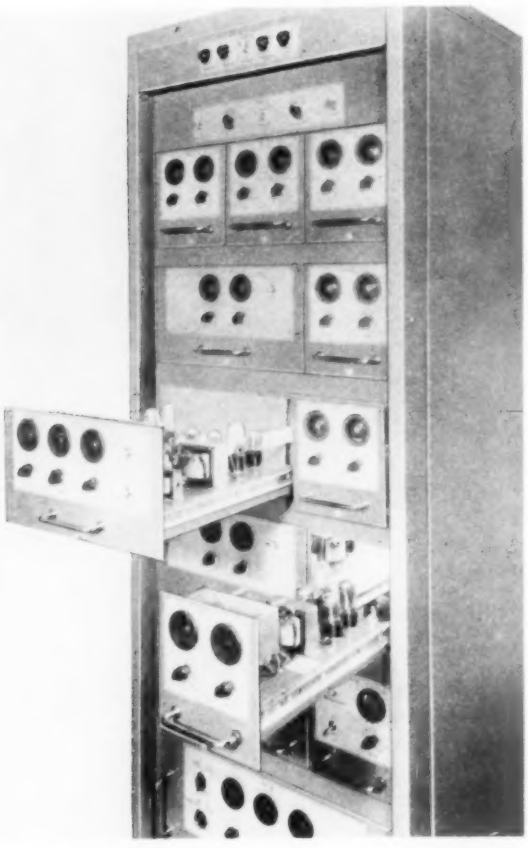


Fig. 5 Timer cabinet with drawers open for observation

type units are 100 count units, designed to give a count by pulses from 1 to 100. Figure 3 is a photograph of an "A" type 100 count unit. All units are built on individual, identical chassis, which are on sliding drawers. The drawers can be pulled out for inspection without disrupting the operation of the control. Each chassis has two neon lights inside the panel, which indicate whether a pulse was received and passed on to the next stage. This simplifies maintaining the unit, because the service engineer may pull out the drawer during an actual run and observe how far the sequence has progressed.

The "B" units are 10 count, which permit the counting of 1 to 10 impulses of current. They are used in conjunction with preheat, weld and postheat functions to count the number of impulses of those functions. They are also identical and interchangeable. Figure 4 is a photograph of a heat, cool, current-decay chassis.

Use of cold cathode tubes eliminates the problem heretofore experienced with the use of R. C. timing networks. Counting-tube circuitry insures accurate timing, since it is monitored directly by line frequency of the power line; and, like an electric clock, can vary only as the line frequency varies. Furthermore, counter tubes give an instant, visual check-out of all timing circuits before an actual production run and without the use of any special instruments. Thus, the welding engineer may observe the exact count of each function before an actual weld takes place, during a weld, or immediately after a weld. All guesswork as to how many cycles of any function occurred is eliminated.

The "C" units, which were shown in Fig. 2, are phase-shift heat adjustors which work into the heat control and firing circuits. These adjusters are also interchangeable and identical. All the individual building blocks shown in Fig. 2 are plug-in and easily removable, so that when any trouble occurs on the firing line, a spare unit can easily be inserted within a matter of seconds to replace one which may be defective or inoperative. Figure 5 is a photograph of a frequency-converter welder control showing the sliding drawers pulled out for inspection.

Counter-Tubes Basic Circuitry

Figure 6 is an illustration showing the electrical and physical connections to a typical counter tube. The counter tube is a low-current, low-heat, cold-cathode-glow transfer tube. It has an anode in the center, surrounded by 10 cathodes and 20 guides. You will note that all guides labeled *G1* are tied together; and, similarly, all guides labeled *G2* are tied together. The guide cathodes *G1* and *G2* are biased above the main

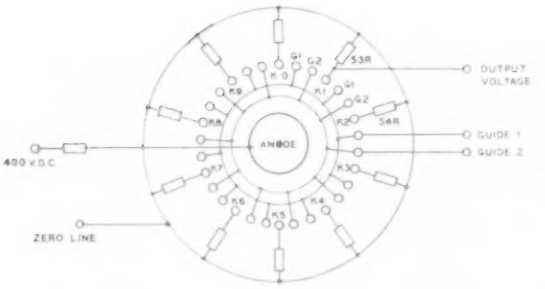


Fig. 6 Counter-tube arrangement and connections

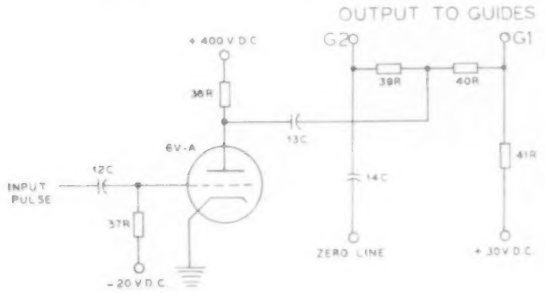


Fig. 7 Counter-tube driving circuit

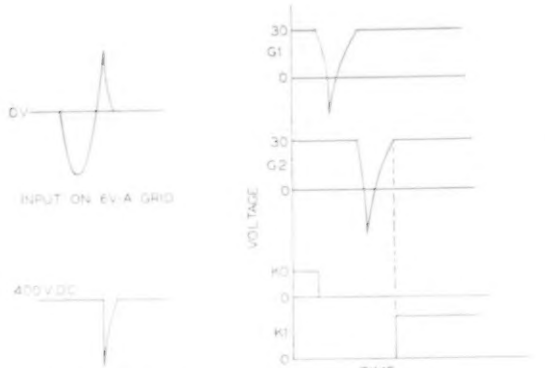


Fig. 8 Voltage curves affecting counter tube

cathodes K_0-K_9, etc. When Cathode 1 is energized, there is a potential difference across $53R$ of about 25 v. This potential appears across any cathode that is conducting or glowing. Transfer of the negative pulse from $G1$ to $G2$ causes the glow to follow. Removal of the pulse from $G2$ permits the glow to continue on to the next main cathode. The preferential influence, or most negative point of the ionization near K_1, causes the glow to settle on K_1 rather than return to K_0. The glow will then remain on K_1 until the sequence is repeated for the next set of guides. At rest, the counter tube glows between the K_0 and the anode.

Counter-Tube Switching

Counter-tube switching is accomplished by circuit utilizing a charging tube $6VA$, which conducts sharply when a pulse of desired wave shape is introduced into the control grid circuit. Figure 7 shows the basic circuitry. An incoming pulse overrides the grid bias voltage of about minus 20 v. The output of $6VA$, which is one-half of a $6SN7$ tube, is so arranged that Guide 1 is driven negative. Time constants are so chosen that Guide 2 is driven negative shortly thereafter, causing the glow to transfer to $G2$. When the negative pulse is removed, the glow is transferred to K_1. For each pulse from tube $6VA$, the glow on the counter tube is moved over one cathode. The left-hand side of Fig. 8 shows the input on the grid of $6VA$ the output on the plate of that tube, which is applied to the guides through coupling capacitor $13C$. The right side of Fig. 8 shows the instantaneous voltage wave which accomplishes the glow transfer. Refer back to Fig. 7. When counter tube is reset, glow is at zero. When $6VA$ conducts, the charge on $13C$ and $14C$ reverses, sending a negative pulse to Guide 1, causing the glow to transfer from cathode zero to Guide 1. An instant later, because of capacitor $14C$ charging at a slightly different time, a pulse is sent to Guide 2, causing the glow to transfer to Guide 2. The preferential influence of ionization near cathode, will cause the glow to settle on K_1. The glow will remain on K_1 until the sequence is repeated for the next set of cathodes. The next incoming pulse causes $6VA$ to conduct sharply. The charges on capacitors on $13C$ and $14C$ reverse, sending a negative pulse to $G1$, causing the glow to transfer to $G1$; and shortly thereafter, the charge on $14C$ sends a negative pulse to $G2$, transferring the glow to $G2$. Removal of pulse from $G2$ causes the glow to go on to K_2. The negative transfer pulse is applied to all $G1$'s and then $G2$'s simultaneously. A glow from anode to only one cathode can be maintained at any given time. The primary influence of the discharge moves the glow to the guide cathode which is closest to the discharge. The primary influence is due to the principle that ionizing of gas-filled tubes is lowered if ions are already present in the ion cathode gap. A glow discharge can then be made to move from one guide to an adjacent one by means of a negative voltage pulse on the new cathode, provided that the electrons are able to diffuse into this new anode-cathode gap. It can be seen that the discharge glow can be made to move in succession from 0 around about a common anode by a successful application of pulses to each cathode. When the desired count is reached, electronic switching discontinues the negative pulse which triggered the counter thereby terminating the count. Several counter tubes may be connected in cascade to increase the total from 9 to 99, or as far as necessary to arrive at the desired count total. The successive application of negative pulses drives the glow starting from 0 around to a total count for the first tube. At cathode 0, a pulse is sent to an amplifier tube. Two negative pulses are sent to the tens count tube, transferring the glow from 0 to first cathode to record a count of 10. After the units count tube runs up, another count of 10, a pulse is again sent to the amplifier tube and the sequence is repeated. It is thus possible

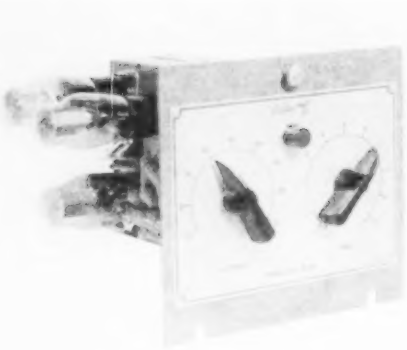


Fig. 9 Plug-in heat adjustors

Fig. 10 Heat control and ignitron contactor cabinet

Fig. 11 Complete spot-welder control

to obtain any desired total count.

Heat-Control Circuitry

The problem of unbalance was tackled by designing a new three-phase heat-control system in which variations in thyratron-tube characteristics do not affect the phase-shift angle of firing. Two identical thyratron tubes may have varying characteristics. An RC network, which was formerly used to delay firing so that transients would not trigger firing tubes, is not used since resistor and capacitor values may change, causing variations in positive and negative pulses. A simple potentiometer adjustment is provided for correcting an unbalance caused by variation in transformer characteristics. The d-c phase-shift network is inherently self-regulating, thus if line voltage varies, the heat control will function inversely in such a manner as to compensate for such variations. Figure 9 is a photograph of a plug-in heat adjustor. Separate, identical heat-control adjustors provide for each of the heat functions of preheat, weld and postheat. The panels consist of a coarse heat tap switch, vernier potentiometer and neon indicator light to show when the unit is operating. As with the timing plug-in units, all heat controls are plugged in and interchangeable for ease in maintenance and flexibility. Figure 10 shows the ignitron contactor and firing panel of the three-phase frequency-converter welding control. Figure 11 is a photograph of the complete three-phase frequency-converter control panel using counter tubes. It is made up of two cabinets, one housing the timing circuits the other the heat control and ignitron contactors. Figures 12 and 13 are application photographs showing the three-phase frequency-converter panels as being used by welding-machine manufacturers and aircraft manufacturers. Taking into consideration the fact

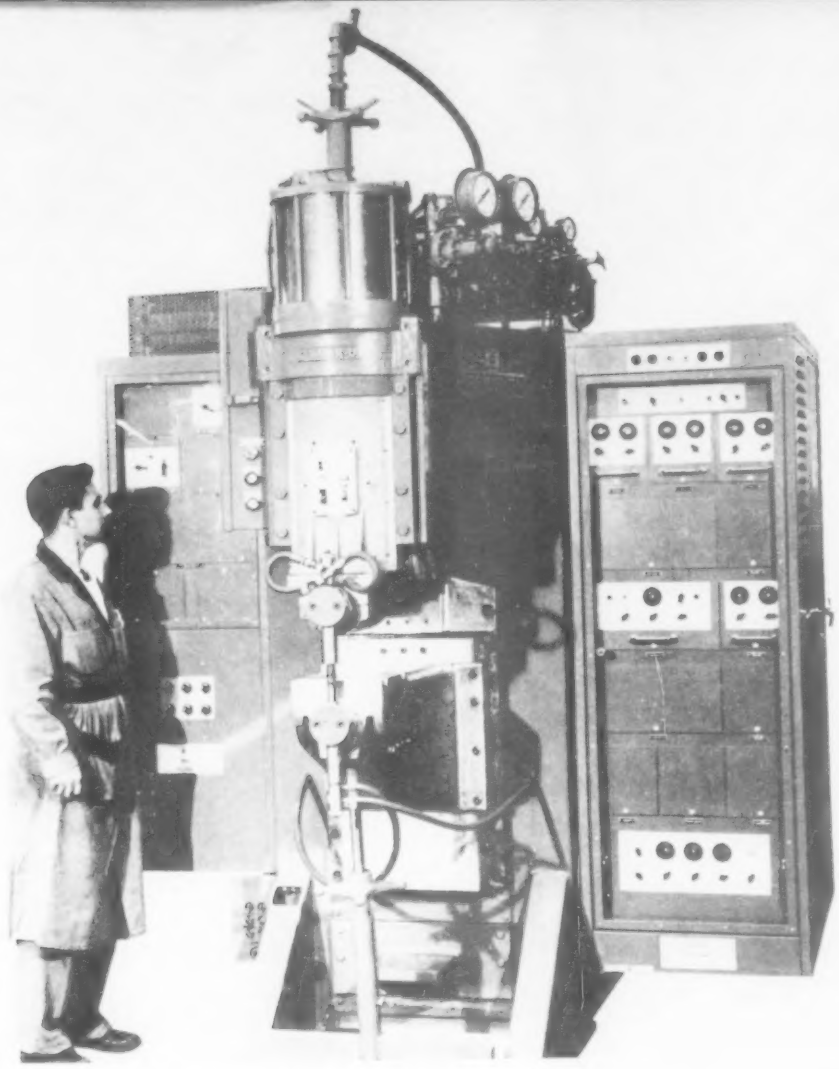


Fig. 12 Basic spot-welder control on resistance-welding machine

that new developments are taking place in alloy-welding techniques, the circuitry in this control has been designed so that up and down slope and other accessories may be incorporated when desired.

Summary

1. The design of the over-all control was such that all the functions were put in individual building blocks in order to eliminate complexity of circuitry.

2. Counter tubes were substituted for R. C. timing networks in order to give accurate, dependable timing on all functions.

3. The counter tubes are so mounted that each sequence can be seen as it occurs so that a visual record can be had of each operation, giving the exact timing which occurs during that operation.

4. The phase-shift heat-control system was improved to compensate for component inaccuracy. The phase-shift heat-adjustor panels were made easily removable. Neon lights were used wherever feasible so that the operator could follow the operation visually.

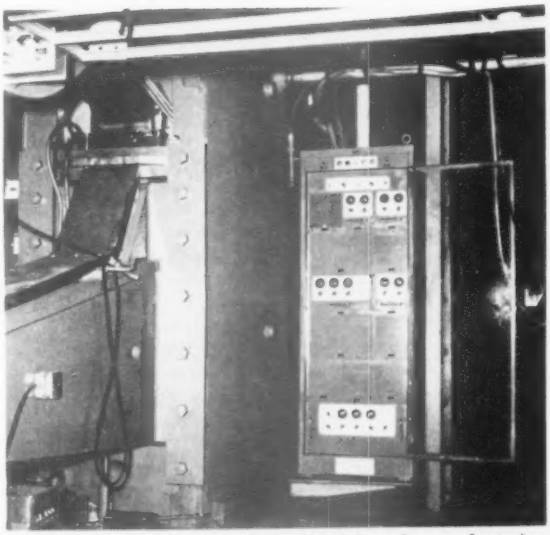


Fig. 13 Control on machine used in aircraft manufacturing plant

Convair's B-58 in flight

TUNGSTEN-ARC WELDING OF 0.002-IN. AND 0.005-IN. STAINLESS STEEL AND TITANIUM

Old concepts of thin-gage welding changed to cope with the ever-increasing demands of the modern aircraft industry for maximum strength and minimum weight in a welded joint

BY JAY C. COLLINS AND S. P. JENKINS

ABSTRACT. The cover of THE WELDING JOURNAL is 0.005 in. thick. That is just right for a magazine cover but pretty slim from the standpoint of welding the same thickness of 17-7 PH stainless-steel sheet. To complicate matters, this weld must be made without the use of a filler rod because of aerodynamic requirements. In addition, the weld-bead reinforcement must be held to −0.001 in. or +0.003 in. tolerance for the 72-in. lengths required, and the 1.1% aluminum content of the base metal must be retained to achieve the required maximum heat-treat response. Prior to this assignment, 0.015 in. was considered to be the ultimate in thin-gage welding. These welds are used as exterior skins for the brazed honeycomb panels that go into the construction of Convair's B-58 supersonic bomber.

Our efforts here are to show how welding has once more met the challenge of a seemingly impossible joining problem, and how old concepts of thin-gage welding had to be changed to cope with the ever-increasing demands of the modern aircraft industry for maximum strength and minimum weight in a welded joint.

Jay C. Collins is Manufacturing Research Engineer and **S. P. Jenkins** is Project Manufacturing Research Engineer, Convair, Fort Worth, Tex.

Paper to be presented at the 1958 AWS Annual Spring Meeting to be held in St. Louis, Mo., April 14th to 18th.

Problem

Maintaining exterior skin smoothness for aerodynamic requirements was a prime factor in this assignment. Since several brazed-panel dimensions exceed the 24 in. maximum available width of 0.005-in. 17-7 PH stainless steel, an aerodynamically smooth butt-welded splice became necessary.

A resistance roll-seam lap-joint weld was considered first, but would not meet the aircraft designers' aerodynamic requirements which specify a plus 0.003-in. tolerance to avoid excessive skin friction and pos-

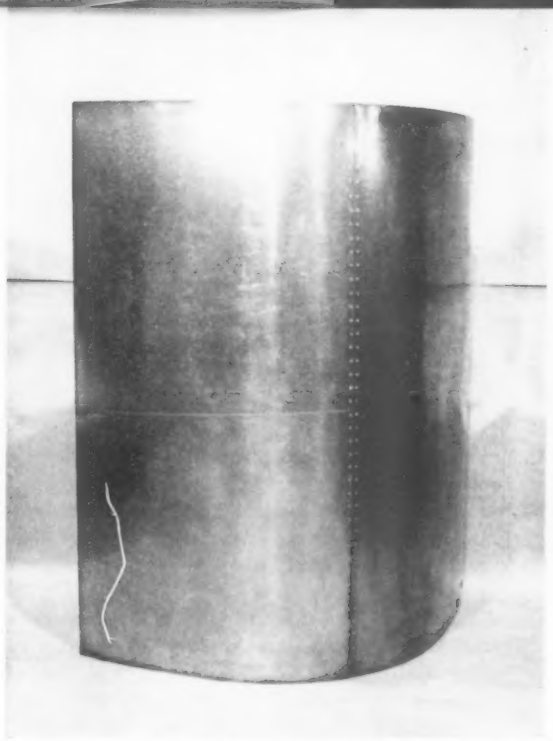


Fig. 1 Welded joint of 0.005-in. stainless steel shown on typical engine-nacelle panel

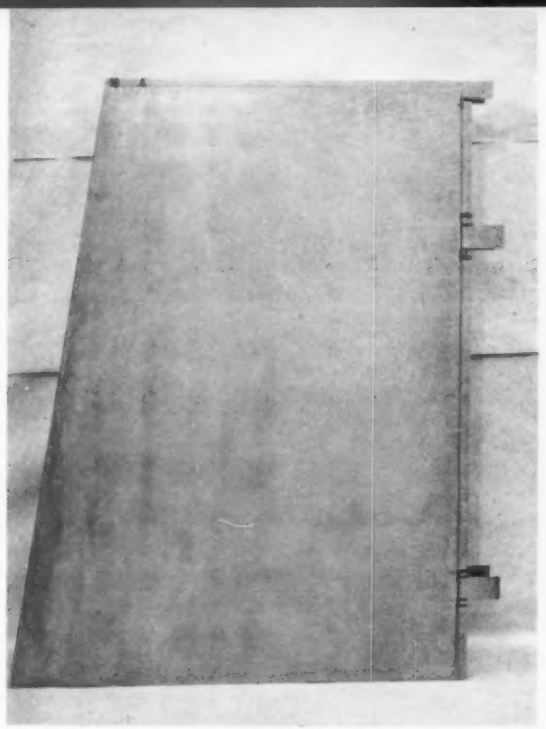


Fig. 2 Welded joint of 0.005-in. stainless steel shown on elevon panel

sible flutter at supersonic speeds. Two typical panels are shown in Figs. 1 and 2.

Holding Fixture

Preliminary experiments indicated that special fixturing would be necessary to hold the weldments in correct alignment during the welding cycle. A holding fixture (Fig. 3) was designed to use a series of stainless-steel clamps 2 in. wide in order to hold the sheets firmly in place without upset pressure. The clamps derive their power from a fire hose connected to the shop air supply and backed up so as to actuate the clamp arm in clamping the material. Spring loading was used to return the clamps to an open position when the air in the hose was exhausted. Caution had to be taken in setting the clamp pressure so as to avoid fixture deflection. Maximum line pressure was found to be 15 psi.

A side beam and carriage were mounted on the holding fixture. Extreme care was used to insure vertical and horizontal alignment between the top of the side beam and the centerline of the backing bar.

Since a fixed welding head was used, any variation in the vertical plane resulted in a variable arc voltage. The dimensional tolerance in this plane was held to less than 0.003 in. The carriage installation gave us a constant head travel rate from 0 to 60 ipm.

Power Source

A survey of welding machines was conducted to determine the machine best suited to our task.

Arc stability at low operating current was used as a determining factor in selecting the power source to be used. Motor generators, transformers and rectifiers of several types were tested.

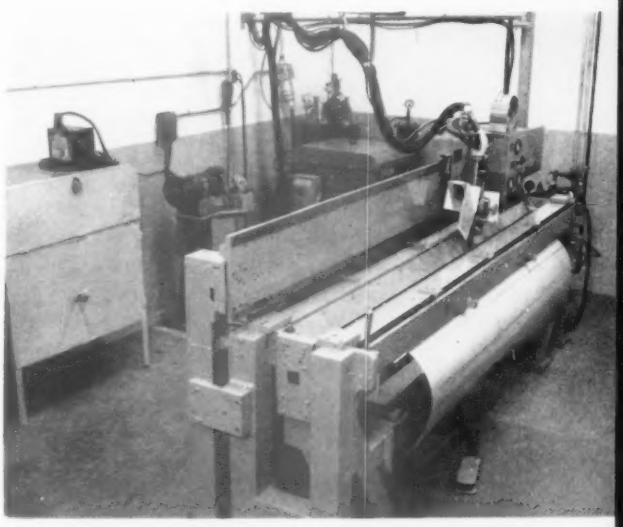


Fig. 3 Welding fixture with stainless steel clamped in place prior to welding (patent pending)

A selenium rectifier with a special $^1/_2$- to 8-amp tap was found to have the required arc stability and the shortest recovery time of all machines tested. This machine is used as a power source and has operated several hundred hours with trouble-free service.

It is well to point out that a high power factor for the primary side of the power source is an absolute necessity on an installation of this type. The mini-

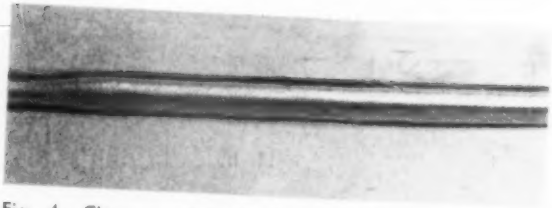


Fig. 4 Close-up of finished weld. *Note:* Starting cycle and transition from argon to helium as the shielding gas

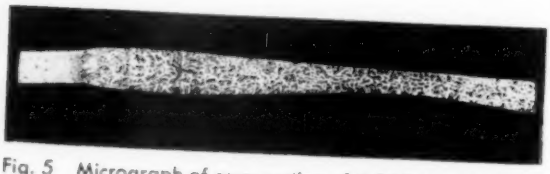


Fig. 5 Micrograph of cross section of 0.005-in. weld made without a flange. *X75.* (Reduced by 1/2 upon reproduction)

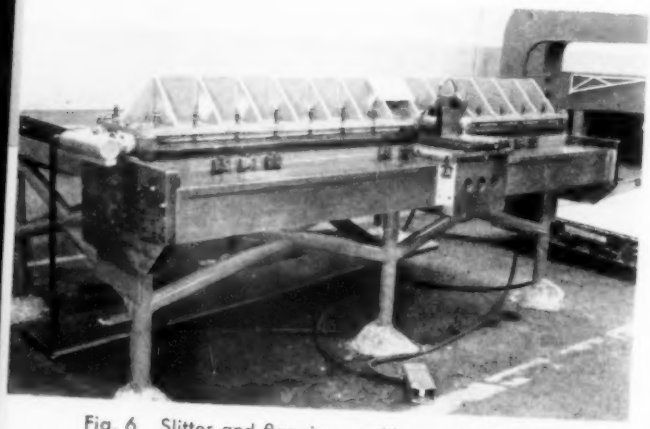


Fig. 6 Slitter and flanging machine used for edge preparation

Fig. 7 Micrograph of cross section of 0.005-in. stainless-steel weld made with a flanged material. *X75.* (Reduced by 1/2 upon reproduction)

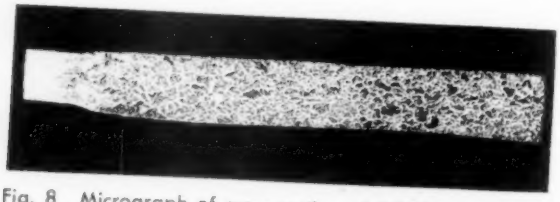


Fig. 8 Micrograph of cross section of 0.008-in. stainless-steel weld made with flanged material. *X75.* (Reduced by 1/2 upon reproduction)

mum factor consistent with precision operation is 85%.

Shielding Gas

Argon was first tried as both a root and face shield but was found to result in a relatively cold arc. Due to this characteristic, a very small bead was obtained and it was difficult to keep the electrode centered on the joint.

Argon was then mixed with helium in various proportions but this resulted in off-color welds and cross-sectional variations through the weld.

Helium was then tried as a face shield and argon as the root shield. The quality was adequate; however, the appearance was only fair and the weld section was not uniform throughout the full length of the bead. Examination of cross sections revealed considerable variations in the thickness of the bead reinforcement. This particular condition was traced to the unequal cooling effect of the two gases.

Helium was then tried for both root and face shields with consistently satisfactory results.

One of the principal problems when using bottled helium is moisture content. While usually dry enough for the average welding application, the small amount of moisture content could not be tolerated for our purpose.

This condition was corrected by circulating helium through a dryer containing silica-gel as a desiccant.

Arc Initiation

Arc initiation at the low operating current was another problem. We had established the fact that helium was definitely superior as the shielding medium for 17-7 PH stainless steel, but, unfortunately, helium will not provide sufficient ionization to establish current flow even with superimposed high frequency. As an alternate, touch starting was tried but could not be used because of electrode contamination.

Satisfactory starting is obtained by using argon and timed high-frequency current in conjunction with a gas-transfer valve. This valve allows argon to be used for initiating the arc, and then a switch is made to helium to make the actual weld. The starting cycle is usually timed for 15 sec, which has proved to be ample time for the electrode to reach operating temperature. Figure 4 shows the transition point where the switch from argon to helium is made.

High-frequency current, while an excellent starting aid in this process, adds nothing to the stability of the arc, so it is timed off at the instant the gas transfer is made.

Electrode

Various diameters and types of tungsten electrodes were tested. It was found that a 2% thoriated 0.040-in. diam. ground or polished-finish tungsten electrode is adequate. However, the geometry of this electrode is very important. It must be ground to a 60-deg point and polished to a scratch-free surface. For optimum performance it should be polished with fine emery

Table-1—Tensile-Test Results

17-7 PH Stainless Steel; Butt Welds—No Flange

Test no.	Gage	Weld position	Yield, psi	Ultimate, psi	Elongation, %
		Annealed condition, as-welded			
1	0.005	Normal	65,600	120,900	18.5
2	0.005	Normal	60,200	122,500	23.0
3	0.005	45 deg	52,600	135,600	36.0
4	0.005	45 deg	60,000	132,000	30.0
5	0.005	Parallel	60,200	140,600	31.0
6	0.005	Parallel	60,000	138,000	28.0
1	0.008	Normal	66,700	108,000	17.0
2	0.008	Normal	71,100	118,500	23.0
3	0.008	45 deg	59,000	138,000	10*
4	0.008	Parallel	66,700	104,400	20
		Heat Treated to TH 1050 condition			
1	0.005	Normal	160,600	161,600	5.5
2	0.005	Normal	163,300	169,400	4.0
3	0.005	45 deg	163,900	194,700	6.5
4	0.005	45 deg	167,400	171,500	6.0
1	0.008	Normal	165,800	170,900	7.0
2	0.008	Normal	173,400	184,700	7.5*
3	0.008	45 deg	143,600	157,400	8.0
4	0.008	45 deg	123,300	178,500	7.0

* Weld failure.

cloth before each weld. Electrode extension from the ceramic cup must not exceed $\frac{3}{16}$ in. because of the possibility of electrode deterioration due to overheating.

Welding Head

A welding head was modified to improve gas coverage and to use a $\frac{3}{8}$-in. ID ceramic cup. This modification also included provision to use "O" rings as a seal to insure a gas-tight system. This is very important as any aspiration or leaks in the gas system will cause an off-color weld immediately.

Operators are trained to gage degrees of shielding efficiency by the color of the weld. It was found that any intermediate color between light tan and bright silver would give the required physical characteristics for this type of joint. A consistent light silver color is obtained on all production work (Fig. 4). This color factor, while not 100% conclusive, is a very good on-the-spot visual check of weld quality.

Joint Configuration and Edge Preparation

Edge preparation of the thin-gage sheet is an important function that affects the success of this type of welded joint. Several types of edge preparation were tried, including (1) grinding, (2) milling, (3) shearing, (4) blanking and (5) slitting. It was found that, on a production basis, slitting will provide the most reliable method of edge preparation.

Original planning called for a plain butt joint to be used, but after several test panels were welded, it was found that

1. A plain butt joint resulted in excessive thinning through the weld section (Fig. 5).
2. Edge mating was extremely difficult to obtain on a production basis and setup time was increased because of the possibility of lapping the material.
3. X-ray quality was questionable due to the lack of uniformity through the weld section. Tensile-specimen results were low with a wide spread on elongation values. Roll plannishing improved this situation, but did not eliminate it entirely (Table 1).

A flange-type joint was tried and found to be very satisfactory.

The slitter used for preparing the plain butt joint was modified to provide a flanging roll for forming a flange after the slitting operation (Fig. 6).

The amount of flange height is governed by the reinforcement desired through the weld section.

A flange three times the material thickness will hold the finished weld to the dimensions required (Figs. 7 and 8).

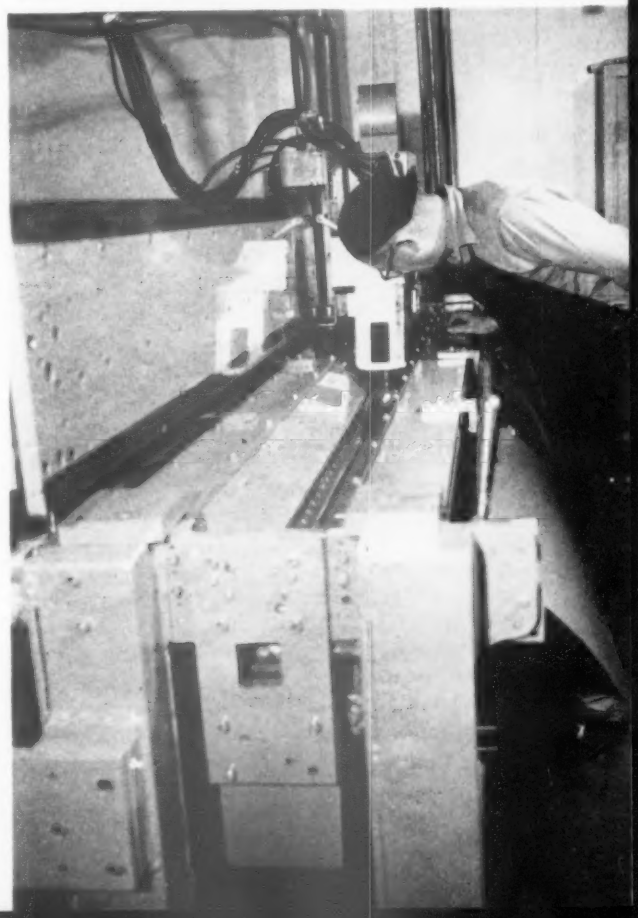
A flange is not used on titanium because of flange forming difficulties. However, tensile values of a plain butt joint exceed those of the base metal.

Welding Technique

Due to the precise nature of thin-gage welding, it is mandatory that only an experienced manual inert-gas tungsten-arc welder be used as an operator.

While this process is mechanized, it cannot by any means be considered automatic or semiautomatic. The machine in operation is shown in Fig. 9. The quality of the finished weld depends on the judgment of the operator and such variables as:

Fig. 9 Weld in progress



1. Electrode setting or extension of the tungsten electrode from the ceramic cup.
2. Travel (speed of welding).
3. Flow rates of shielding gas.
4. Fit-up. Flanged material in the fixture under full clamp pressure must mate to form a joint with less than a 0.004-in. gap. Any gap in excess of this will cause thinning through the weld section.
5. Arc-gap setting. For optimum welding conditions this dimension should be 0.040 in.
6. Weld speed. Travel rate and arc voltage must be adjusted after the arc is started.

All of the above variables are left to the judgment of the operator but are vital to the quality of the finished weld.

Backing Bar

A gas backing must be used and will serve a dual purpose. One, it will protect the root side of the weld during the welding cycle and, second, it will provide controlled postweld cooling. This backing must be aspiration free or an oxidized weld root will result.

Backing-bar material and the geometry of the groove have a direct bearing on the finished weld. Considerable experimentation was conducted on the shape of the backing groove. Circular, square and rectangular grooves were all tried. The best results were obtained with a rectangular groove 0.015 in. deep and 0.125 in. wide, with 0.050-in. gas holes drilled 0.500 in. apart along the full length of the bar.

Mild steel, stainless steel and copper were tested as backing-bar materials and copper has proved to be the best for our purpose.

Control Panel

Since no stock or commercial control panel would incorporate the various controls required, it was necessary to design and build a control system to coordinate the following (Fig. 10):

1. Welding contactor.
2. Purge.
3. Transfer valve.
4. Underbead shield.
5. Travel.
6. High-frequency timer.
7. Gas-transfer timer.

Qualifications

Since this type of joint was not covered by Military Specifications, the welds were subjected to extensive testing to obtain complete results for qualification of this process.

For instance, tensile-fatigue specimens were subjected to stresses ranging from 20,000 to 80,000 psi for a minimum of 250,000 cycles.

A corrosion test was also made; intergranular corrosion test specimens were immersed in boiling copper-sulfate solution for 24 hr.

Tensile coupons developed a minimum ultimate stress greater than the 180,000 psi required (Tables 2 and 3).

Table 2—Tensile-Test Results

17-7 PH Stainless Steel; Flanged Butt Welds

Heat treated to TH 1050 condition

Test no.	*Gage*	*Yield, psi*	*Ultimate, psi*	*Elongation %, 2-in. gage length*	
1	0.005	212,900	248,600	2	
2	0.005	242,900	245,700	1	
3	0.005	245,700	248,600	1	
4	0.005	207,700	213,100	4	
5	0.005	206,600	211,600	4	
6	0.005	208,000	216,000	4	
7	0.005	200,700	210,800	3	Corrosion specimens
8	0.005	202,800	212,900	2	Corrosion specimens
9	0.005	200,500	217,000	3	Corrosion specimens
10	0.005	200,800	210,800	2	Corrosion specimens

Table 3—Tensile-Test Results

17-7 PH Stainless Steel; Flanged Butt Welds

Heat treated to TH 1050 condition

Test no.	*Gage*	*Yield, psi*	*Ultimate, psi*	*Elongation %, 2-in. gage length*	
1	0.008	197,100	214,500	2	
2	0.008	197,100	214,500	2	
3	0.008	196,900	214,600	2	
4	0.008	202,500	219,500	3	
5	0.008	200,000	217,500	2	
6	0.008	204,500	222,200	3	
7	0.008	204,000	218,000	3	Corrosion specimens
8	0.008	202,000	214,000	2	Corrosion specimens
9	0.008	204,400	216,400	3	Corrosion specimens
10	0.008	203,200	217,300	2	Corrosion specimens

Elongation across the weld was equal to or exceeded the 1% minimum allowable over the 2-in. gage length.

No repairs are allowed on the weld; however, rejection rate is very low. In event of a faulty weld, it can be sheared out and rewelded with a minimum loss of material and time.

Operating Conditions

The following are typical operating conditions.

0.002-in. stainless steel:

3 amp
7 v
6 cfh helium, face shield
4 cfh helium, root shield
28 ipm welding speed
1/4-in. ID ceramic cup size
d-c current, straight polarity

0.005-in. stainless:

5 amp
10 v

11 cfh helium, face shield
8 cfh helium, root shield
24 ipm welding speed
$^5/_{16}$-in. ID ceramic cup
d-c current, straight polarity

0.008-in. stainless:

8 amp
12 v
11 cfh helium, face shield
8 cfh helium, root shield
20 ipm welding speed
$^5/_{16}$-in. ID ceramic cup

0.008-in. commercially-pure titanium:

10 amp
14 v
11 cfh helium, face shield
8 cfh helium, root shield
16 ipm welding speed
$^5/_{16}$-in. ID ceramic cup
NOTE: No trailing shield is necessary

While 0.002-in. stainless steel has been successfully welded using this technique, it is not a production item at the present time.

Considerable commercially-pure titanium of heavier gage sheet has been welded as well as weldability evaluation on DOD alloys, such as

1. 6Al4V
2. 6Mo3Al
3. 4Al3Mo1V
4. 5Al2.5Cr1.5Fe
5. 16V2.5Al

Summary

It has been found that the Convair-Fort Worth developed type of fixturing is suitable for weldability comparisons of new materials. It is possible to obtain and duplicate optimum welding conditions not possible by manual techniques.

Accurate control can be obtained over:

1. Travel.
2. Welding current.
3. Arc gap.
4. Shield contamination.
5. Other variables inherent to manual or wire-feed applications.

The method satisfies all the following:

1. Requires no operator dexterity and gives optimum control over application of welding heat.
2. Distortion of the base metal adjacent to the weld is held to an absolute minimum.
3. Normal inspection procedures reveal all inconsistencies in technique as well as all inherent defects.
4. Destructive tests of all types and degrees on this joint prove it superior to stainless-steel welds joined by inert-gas tungsten-arc welding using filler wire.
5. Statistics compiled from the welding and testing of the numerous development and production joints made using this technique indicate definitely that consistency of quality of the weld structure and accurate dimensional control are assured characteristics of this method.
6. This slow-speed, low-current technique in the field of precipitation-hardening materials proves to be the answer to getting high-tensile strengths in weld areas.

As the performance demands of modern aircraft and missiles increase, the weight saving becomes more important.

Mechanized welding is proving to be the only way to fabricate many of the components of airframe construction.

Operational requirements involve extremely high skin temperatures. This and other environmental factors associated with supersonic flight has made the use of precipitation-hardening stainless steel mandatory for exterior skin use.

The ability of this welding process to meet the joint requirements of these severe high-temperature service conditions has been recognized by design engineers at Convair. As a result, it is used extensively on the B-58 and will be used more on airplanes and missiles of the future.

We are happy to report a definite trend among aircraft design engineers to look to welding for the answer to their joining problems. We foresee a time in the immediate future when an all-welded modern airplane or missile will be a reality.

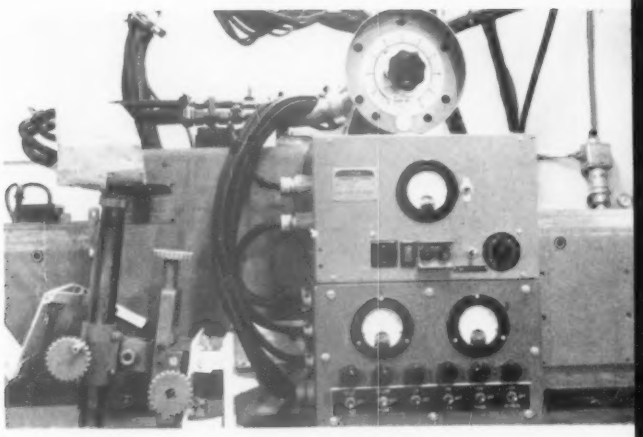
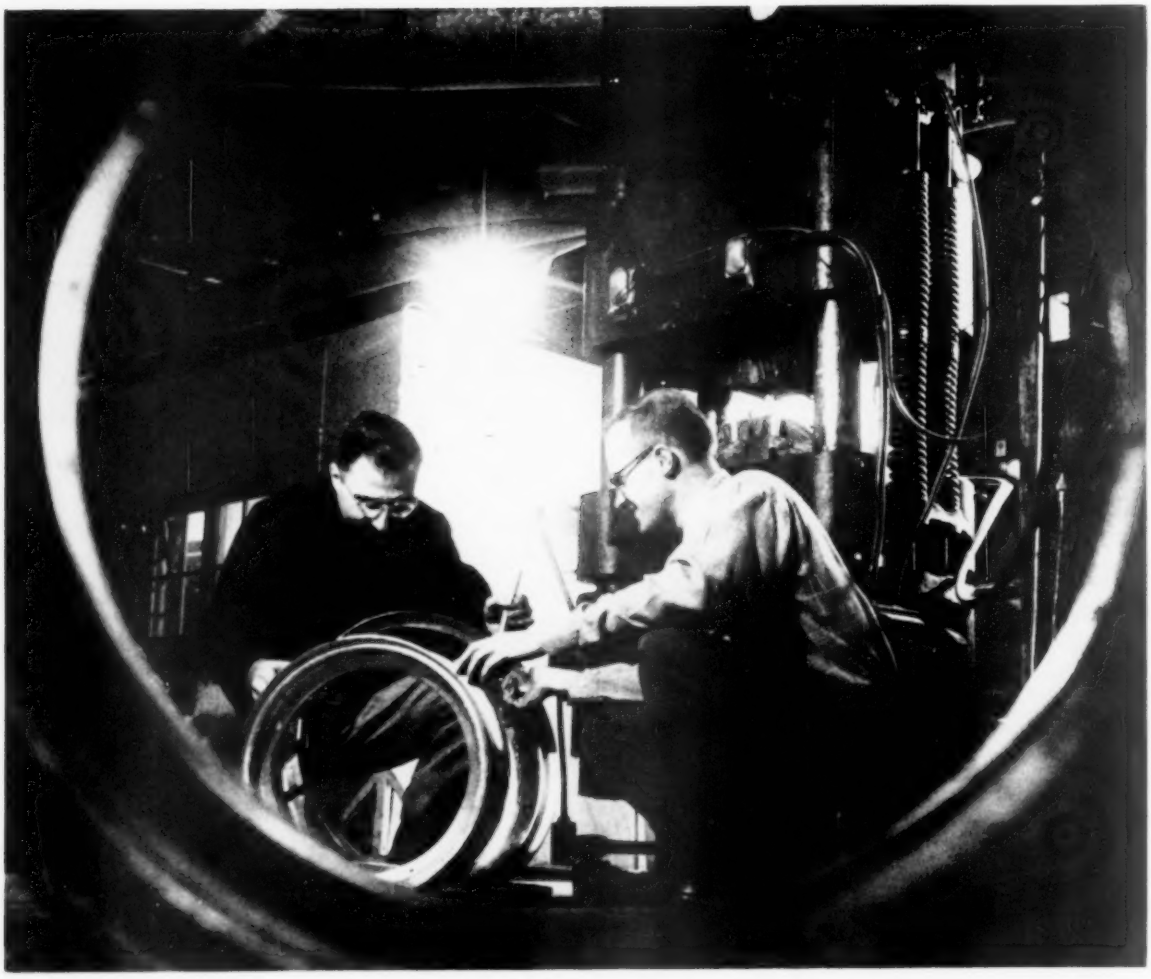


Fig. 10 Control panel

Acknowledgment

The writers with to express their gratitude to the Manufacturing Research and Development Department of the Fort Worth plant of Convair, a Division of General Dynamics Corp., for the opportunity to develop this process and for permission to present this article.

Acknowledgment is also given to A. W. Anderson, service engineer for the Linde Co., for his encouragement and valuable assistance in the work reported in this article.



New forge-welding development applied to wheel-rim fabrication

NEW FORGE WELDING OF ALUMINUM AND MAGNESIUM ALLOYS

Welds made in high-strength aluminum alloys and high-strength magnesium alloys by this forge process reported to have developed 95 to 100% joint efficiencies

BY L. A. COOK AND D. G. SHAFER

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Paper to be presented at the 1958 AWS Annual Spring Meeting to be held in St. Louis, Mo., April 14–18.

* Developed and patented by Ravens-Metal Products, Inc.

ABSTRACT. A new forge-welding process for welding high-strength aluminum and magnesium alloys has been developed.* This forge welding consists of heating the parts to be welded to a temperature which is high enough to allow good uniform flow of the materials without cracking and yet the temperature is sufficiently low that the samples are not overaged or partially annealed in the welding process. Careful control of the time, temperature and pressure cycles are important. Welds made in high-strength aluminum alloys and high-strength magnesium alloys by this forge process have developed 95 to 100% joint efficiencies.

For example, welds in 7075-T6 aluminum alloy have been made which possess an ultimate tensile strength in excess of 80,000 psi with an elongation of 5 to 6%. Similar results were obtained in such magnesium alloys as ZK60A-T5, with joint strengths in excess of 50,000 psi and elongations of 11%. Successful welds were also made between high-strength aluminum alloys and high-

strength magnesium alloys to produce joint strengths of 95 to 100%. Metallographic examination of a range of forge-welded high-strength aluminum and magnesium alloys indicates high-quality welds of similar metallurgical characteristics to those obtained in cold welding and flash-butt welding. Many of the major defects normally attributed to these other welds are not apparent in this new forge-welding process.

Based on the experience to date with this new forge-welding process, it is expected that other alloys and alloy systems can be welded to obtain similar high joint efficiencies.

It is anticipated that this process will be widely used in the future for many new products where welding has previously presented a major problem.

Introduction

This new forge-welding technique belongs to the pressure-welding class of processes; however, it is distinctly different from previous cold welding and hot pressure-welding techniques which have been reported. A comprehensive survey of the literature on pressure welding aluminum and other nonferrous materials was conducted and, as a result, it was apparent that cold welding techniques utilized to date had definite limitations based primarily on the fact that a large amount of deformation was necessary in most alloys to obtain a true weld, and that in the cases of the high-strength alloys such as 7075-T6, 2024-T4 (aluminum) and ZK60A-T5 (magnesium), it was impossible to obtain welds at room temperature because of the excessive cracking encountered. On the other hand, a number of investigators had prepared welds in a wide range of aluminum alloys using temperatures of 800 to 900° F with a relatively low upset. These hot processes had the disadvantages of over-aging and annealing the base metals resulting in low joint efficiencies of about 30 to 40%.

The new forge-welding technique differs from each of these processes in that sufficient heat is used in the welding operation to allow aluminum or magnesium alloys to flow without cracking during the welding process; the temperature which is needed for the welding operation is not sufficiently high or of a sufficiently long duration to have harmful effects on the base metal by over-aging or partial annealing. As a result of this modification of careful control of time and temperature in the welding process, successful forge or pressure welds can be made in aluminum and magnesium alloys in all tempers, to produce 90 to 100% joint efficiency.

An additional advantage that this process has over cold welding is that substantially reduced pressures are required to produce a satisfactory weld. It is at once apparent that the temperature and time conditions depend upon the alloy being welded, and in many cases by suitable control of these variables it has been possible to weld dissimilar alloys and even dissimilar-alloy systems.

While a detailed survey of all the information obtained in the literature search is not included here, a bibliography of the reference articles is appended.

One recent publication[1] indicates that for several aluminum alloys weldability is limited because of crack sensitivity or loss in mechanical properties, and that no commonly used welding method has been developed.

For the past ten years numerous investigators have expended a considerable amount of effort to develop techniques for improving the properties of welds in high-strength aluminum alloys. After preliminary investigations on pressure-welding and arc-welding techniques, Martin, *et al.*, were successful in obtaining arc welds in 2024-T4, 7075-T6 aluminum alloys to produce 50 to 60% joint efficiencies. They concluded that they had obtained the maximum joint efficiencies which were possible for these two aluminum alloys, since they had not been able to find any solution for the problem of the heat-affected zone which is produced by most welding processes in these alloys. Several other investigators had confirmed this conclusion so that the only obvious answer to the problem was to use a welding process which does not produce the harmful heat-affected zone. This obviously limited the processes to a form of forge welding or flash-butt welding.

Flash-butt welding had a number of disadvantages, including the high initial cost of equipment, the presence of oxide inclusions and other weld defects unless the process was under careful control. Properties less than 90% efficiency were obtained unless full heat treating and aging after welding were employed.

The obvious conclusion after reviewing all of the work done to date was that a warm forge-welding process held the most attractive possibilities for making high-strength joints in the highest strength aluminum and magnesium alloys without resorting to postweld heat treatment and without excessive cost of equipment, particularly for welds of large cross-sectional area. It is as a direct result of this conclusion that the work on warm forge welding described herein was undertaken.

Equipment and Procedures

Figure 1 shows a detailed view of the welding setup. The welding procedures are relatively simple and are closely related to those used for making cold welds. The samples to be welded are placed in suitable dies

Fig. 1 New forge welding for aluminum and magnesium alloys. Press and die arrangement for $\frac{3}{4}$-in. diam test bars

Table 1—Chemical Composition of Aluminum Alloys Used for Forge-Weld Test Samples

	Percent							
Alloy	*Si*	*Fe*	*Cu*	*Mn*	*Cr*	*Zn*	*Al*	*Mg*
7075	0.3	0.4	1.6	0.2	0.26	5.6	Remainder	2.6
2024	0.3	0.4	4.5	0.6	0.08	0.01	Remainder	1.5
2014	0.8	0.5	4.4	0.8	0.05	0.01	Remainder	0.4
2017	0.6	0.6	4.0	0.6	0.06	0.01	Remainder	0.5
6061	0.6	0.4	0.25	0.11	0.25	0.2	Remainder	1.1

Table 2—Typical Comparative Properties of Welds in 7075-T6 and 2024-T3 Alloys Made by Forge, Flash and Inert-Gas-Arc Processes

Welding process and alloy	*Ultimate tensile strength, psi*	*Yield strength, psi*	*Elongation in 2 in., %*	*Remarks*
7075-T6 new forge	79,800	69,100	5	As-welded
7075-T6 new forge	80,400	69,200	11	Postweld heat treat
7075-T6 base metal	81,700	68,800	13	No weld
*7075-T6† flash	75,300		3.5	As-welded
*7075-T6† flash	78,900		4.1	Postweld heat treat
7075-T6 arc‡	43,400		1.5	Hot short difficult to achieve good weld
2024-T3 new forge	69,400	49,200	10	As-welded
2024-T3 new forge	69,700	47,800	14	Postweld heat treat
2024-T3 base metal	70,000	48,000	18	No weld
*2024-T3 flash	67,800		8.1	As-welded
*2024-T3 flash	65,300		8.9	Postweld heat treat
2024-T3† arc‡	46,600		2.0	As-welded, hot short

* No other commonly-used welding methods have been developed except resistance welding for sheet gages.
† Welding Alcoa Aluminum, 1955 Handbook.
‡ Inert-gas tungsten-arc and metal-arc welding.

allowing sufficient material to protrude above the die face to allow for the forging and welding operation. The mating surfaces of the parts to be joined are thoroughly cleaned and a fresh-machined or filed surface is prepared. Just prior to welding, the surfaces are wire brushed with a stiff wire brush in a similar manner to preparation for cold welding or spot welding. The two faces are then brought into intimate contact and it is desirable that a slight pressure be applied to the interface to avoid the possibility of oxidation during heating. The two stub ends projecting above the die faces are then heated by a suitable means, such as a natural-gas flame, oxyacetylene flame, induction heating or other method. As soon as the stub ends reach welding temperature, pressure is applied, the projecting ends of the samples are upset and the weld is completed.

Welding pressures depend on a large number of factors including the alloy, the temperature at welding, the joint design, the die design and the amount of upset required. Satisfactory welds have been made in aluminum alloys in unit pressures varying from 30 tons per sq in. up to as high as 150 tons per sq in. in some cases. One of the biggest problems is the control of temperature and time at temperature. In practically all cases throughout the development work discussed herein, samples were heated to temperature in less than 30 sec and in most cases in less than 10 sec. Various temperature-measuring devices were investigated and the most suitable method for development and production work was found to be the application of temperature-indicating lacquer to the sample so that the progress of the heating operation could easily be observed.

Where beveling or other joint preparation is feasible or where extruded shapes can be used, it is very often possible to reduce the pressure and die requirements considerably; thus, reducing the cost and increasing the ease of the welding operation.

Forge Welding High-Strength Aluminum Alloys

The chemical composition of the commercial alloys used for this investigation are shown in Table 1. A large number of samples were made in these alloys using various conditions of temperature, upset, surface preparation and heating time, to determine the optimum welding conditions. With a few exceptions, all welds were made in ½-in. diam bar stock. Typical proper-

Table 3—Mechanical Properties of Forge Welds in ½-in. Diam Aluminum Bars Tested As-Welded

Sample	*Alloy*	*Ultimate tensile strength, psi*	*Yield strength, psi*	*Elongation, in 2 in., %*	*Fracture*
1	7075-T6 Lot 1	79,200	69,000	4	Near weld
2	7075-T6 Lot 1	77,400	67,800	4	Near weld
3	7075-T6 Lot 1	77,400	67,800	12	Base metal
4	7075-T6 Lot 1	77,700	67,700	5	Near weld
5	7075-T6 Lot 1	78,700	68,800	10	Base metal
Average lot 1		78,100	68,100	5	102% efficiency
Control sample*		76,000	66,400	13	
1	7075-T6 Lot 2	79,700	69,000	4.8	Near weld
2	7075-T6 Lot 2	79,800	75,000	4.5	Near weld
3	7075-T6 Lot 2	81,000	73,800	5.5	Near weld
4	7075-T6 Lot 2	80,800	73,700	5.3	Near weld
5	7075-T6 Lot 2	79,200	67,500	6	Near weld
6	7075-T6 Lot 2	79,800	66,000	4.5	Near weld
Average Lot 2		80,050	70,900	5.1	
Control base metal		82,600	69,900	19.0	
Average 2024-T3		68,900	48,800	10	
Average 2014-T6		67,000	58,600	9	
Average 2017-T4		61,000	42,000	14	
Average 6061-T6		43,800	39,600	8	

* Calibration of testing machine in this lot was not known, which may account for the relatively low properties obtained here. Some cold work is introduced into the samples which accounts for properties over 100%.

ties of welds made in 7075-T6 and 2024-T3 aluminum alloys are shown in Table 2, as compared to the properties of welds obtained by other welding processes. From the data presented in this table, it can be clearly seen that forge welds made under properly-controlled conditions exhibit properties which are superior to those obtainable by any other process including flash-butt welding, and that heat treating after welding does little to improve the properties except for elongation and ductility of the weld which is appreciably improved.

During the course of the investigation, a number of welds were made at somewhat less than optimum conditions to yield-joint efficiencies of about 90%. In these cases when the samples were solution heat treated and aged after welding, 100% joint efficiency was obtained with elongations of 10 to 12%. The mechanical properties of typical lots of forge-welded test bars in a number of different aluminum alloys is shown in Table 3. From the data presented in this table and also from other similar data, it has become apparent that forge welds can be made on a production basis in any aluminum alloy to produce physical properties between 95 and 100% joint efficiency consistently. With somewhat more careful control where necessary, there is good reason to believe this can be narrowed to 98 to 100% joint efficiency; however, for most applications such close tolerances would not be necessary and the additional cost of process control would not be justified.

An investigation of the effect of time and temperature on the resulting weld properties was conducted for 7075-T6 aluminum alloy. The results of this investigation are shown in Fig. 2. From these curves it can be seen that a welding temperature of 400 ± 40° F.

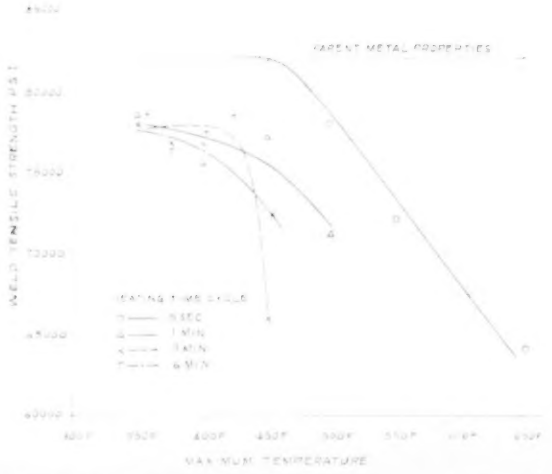


Fig. 2 Effect of welding temperature on tensile strength of forge welds in 7075-T6 aluminum alloy, for a range of cycles. Optimum temperature 350 to 450° F at less than 30 sec heating cycle

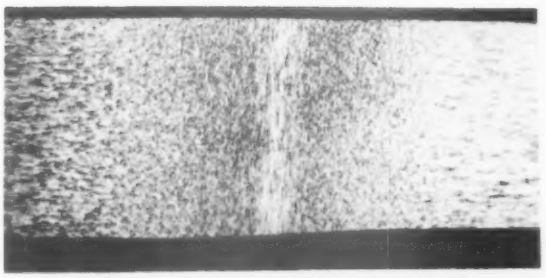


Fig. 3A Photomacrograph of cross section through a forge weld in 7075-T6 aluminum alloy. Keller's etch, 15 sec. X10. (Reduced by ½ upon reproduction)

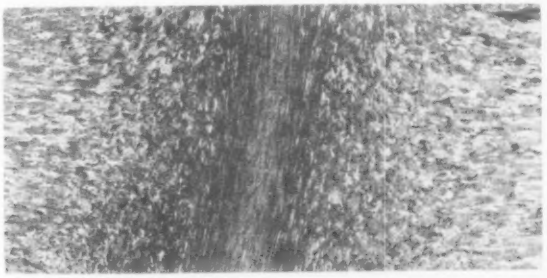


Fig. 3B Photomicrograph of cross section through a forge weld in 2024-T3 aluminum alloy. Keller's etch, 15 sec. X20. (Reduced by ½ upon reproduction)

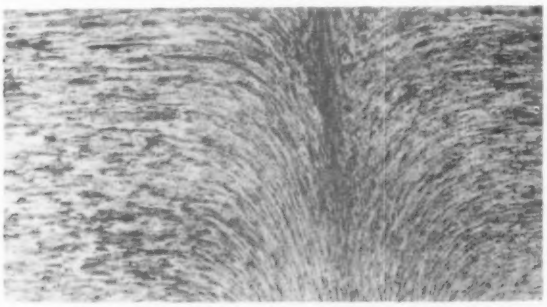


Fig. 4 Photomacrograph of cross section through a forge weld in 7075-T6 aluminum alloy. Section is perpendicular to that in Figure 3. Keller's etch, 15 sec. X10. (Reduced by ½ upon reproduction)

with a total heating time of less than 30 sec will result in optimum weld properties. If lower joint properties are satisfactory, higher temperatures can be used and longer time, if necessary, with lower upset pressure required.

Metallographic Characteristics of New Forge Welds in Aluminum Alloys

Examination of the weld zones shows a metallurgical structure similar to that of cold pressure welds and flash-butt welds. Metallographs of welds in a range of aluminum alloys showed sound weld surfaces with no evidence of any overheating due to the thermal cycles, and it was apparent that good metallurgical bonds had been obtained. The extent of this bonding was so complete that the interface between the two components could not be observed.

Figures 3 and 4 are typical cross sections of new

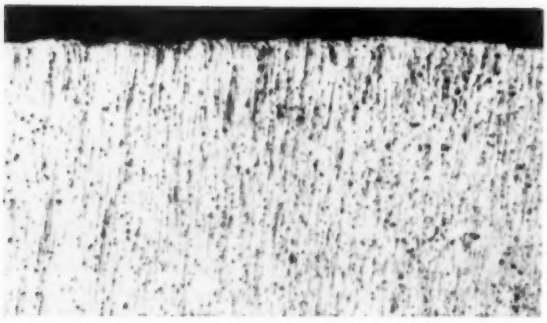


Fig. 5A Photomicrograph of cross section through 7075-T6 aluminum alloy, forge weld. Keller's etch, 15 sec. X100. (Reduced by 1/2 upon reproduction)

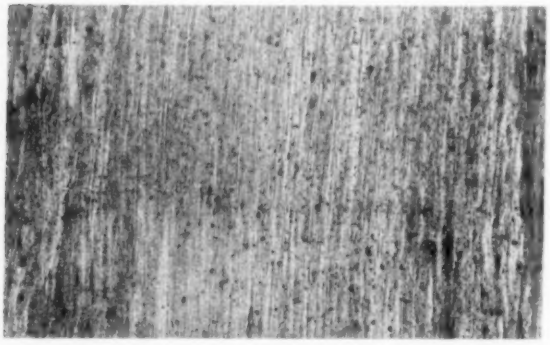


Fig. 5B Photomicrograph of cross section through 2024-T3 aluminum alloy forge weld. Keller's etch, 15 sec. X100. (Reduced by 1/2 upon reproduction)

forge welds in 7075-T6 and 2024-T3 aluminum alloys at magnification of ×10 and ×20 etched in Keller's etch for 15 sec. Macrosections illustrate the grain refinement and transverse flow lines resulting in the forge-welding process. Again, Fig. 5 shows cross sections through the same welds at a magnification of ×100. No evidence of the original interface can be observed in these photomicrographs.

Figures 6, 7, 8 and 9 are sections of a typical forge weld in 7075-T6 aluminum alloy. Figure 6 shows the flow structure of the upset weld, while Fig. 7 shows the wrought structure of the base metal with particles of intermetallic constituents dispersed along the axis of the bar in the direction of working. This should be compared with Fig. 8 which shows the weld-interface region. The intermetallic constituents have been broken up by lateral metal flow during the welding operation and their direction is now perpendicular to the axis of the bar. When the samples were etched, these regions showed a transition from the normal wrought grain structure to transverse elongation in the weld zone. There was no indication of melting or recrystallization, which, of course, was expected because of the nature of the welding process. No discontinuities, interfacial oxide entrainment or inclusions of mechanical defects of any type were found in the micrographs. Figure 9 offers an explanation for this very high degree of weld soundness since the structure shows an intermingling and turbulent flow of metal from the base metal leading to a thorough consolidation at the interface. Interfacial oxide has been forged out and ejected in the flash from the upset deformation.

Fig. 6 Longitudinal section through forge weld in 7075-T6 aluminum alloy heavily etched to show deformation and lateral flow of metal. Caustic etch. X3. (Reduced by 1/2 upon reproduction)

Fig. 7 Photomicrograph of wrought structure of base metal, 7075-T6 aluminum alloy, showing normal longitudinal distribution of intermetallic compounds. Unetched. X250. (Reduced by 1/2 upon reproduction)

X-ray Examination and Hardness Surveys

A number of X-rays were taken of forge welds in various aluminum alloys and no evidence of any defects of any kind could be observed on the radiographs. Indeed, it was difficult from the X-rays to determine the exact location of the weld because of the lack of a cast structure and any other voids or foreign inclusions.

During the initial stages of development of the forge-welding process, a considerable number of hardness tests and surveys were conducted to determine quickly the optimum welding conditions. These hardness measurements were made with Rockwell 15T superficial hardness scale, using a 15-kg load and 1/16-in. diam steel ball. It was soon determined that when the welding variables were under good control, a hardness measurement at the joint interface would give a good indication of the ultimate tensile strength, yield strength and elongation of the sample. Thus, while the hardness of the base metal of 7075-T6 aluminum bar stock averaged

Fig. 8 Photomicrograph showing heavily-deformed metal at centerline of forge weld in 7075-T6 aluminum alloy. Refinement of intermetallic particles and distribution in transverse direction was caused by lateral metal flow. Unetched. X250. (Reduced by ½ upon reproduction)

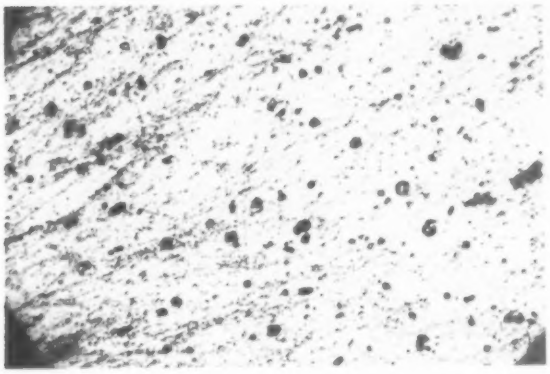


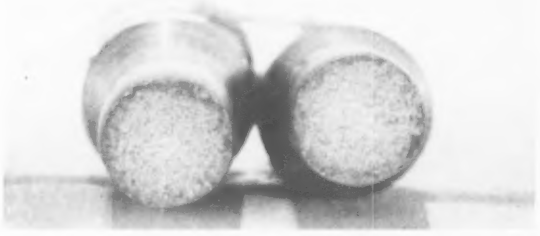
Fig. 9 Photomicrograph of heavily-etched area in forge-weld zone shows turbulent flow and thorough consolidation of base metal (7075-T6 aluminum alloy). The black spots resulted from severe etch attack on intermetallic particles. Caustic etch. X500. (Reduced by ½ upon reproduction)

89 to 90 on the Rockwell 15T scale, the hardness of the weld zone varied from about 84 to 89 depending on the welding conditions. In the case of the samples numbered 1 to 5 as shown in Table 3, the hardness at the joint interface varied from 87 to 88, whereas in the case of samples 6 to 9, slightly lower hardnesses at the joint interface were obtained. Results of these hardness surveys are shown in Table 4. While the exact width of the hardness change for optimum conditions has not been determined, indications are that when the welding process is under close control, any drop off in hardness in the weld zone will be less than ¼ in. in width.

(A)

Fig. 10 Fractured tensile bar of forge weld in 7075-T6 aluminum alloy showing type of fracture which shows no evidence of the original interface

(B)



Typical Fractures and Test Bars

Typical fractured tensile bars of forge welds in 7075-T6 aluminum alloy are shown in Figs 10 (*A*) and 10 (*B*). It should be particularly noted that no evi-

Table 4—Hardness* Surveys Across Forge Welds in 7075-T6, ½-in. Diam Bar

Specimen no.	*Traverse indent position*†													
	0	*0.06*	*0.12*	*0.19*	*0.25*	*0.31*	*0.38*	*0.44*	*0.50*	*0.56*	*0.62*	*0.69*	*0.75*	*0.81*	*0.88*
2	90.0	89.7	89.4	89.0	89.1	87.8	86.7	85.2‡	86.7	87.4	88.8	89.8	90.2	91.1	90.0
9	89.7	89.8	88.6	88.6	87.4	84.1‡	86.2	88.2	88.2	88.8	89.0	89.6	90.3	89.0	89.8
12	90.3	90.4	89.8	89.9	89.6	88.6	87.9	86.8‡	87.0	89.2	88.4	89.1	89.4	89.6	90.1
21	90.6	90.4	90.0	89.4	88.5	88.0	87.7	84.4‡	87.0	87.8	87.8	87.2	90.4	89.8	89.9

C Base-Metal Control Hardness = 89.6 (Average of 5 readings).

* Rockwell 15T scale, 15-kg load, ⅛-in. diam steel ball.

† In axial traverse sequence from identified (stamped) end of bar.

‡ Weld zone.

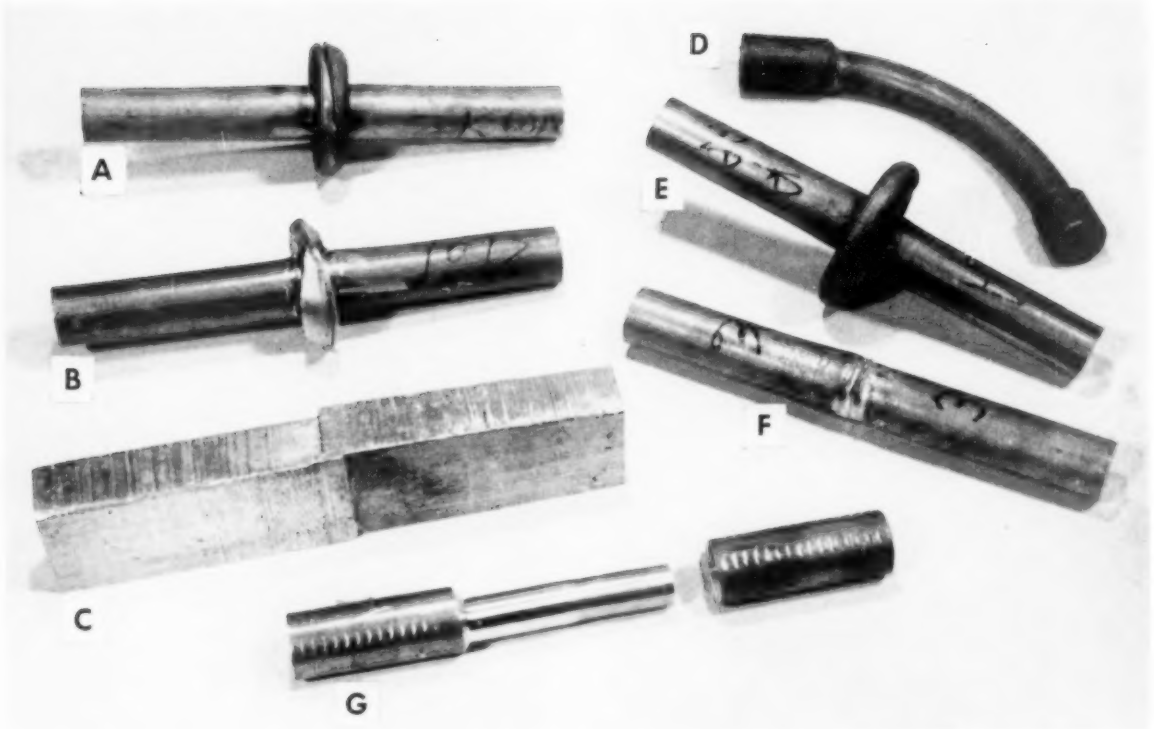


Fig. 11 Typical forge-welded test samples. *A*, ZK60A-T5 as-welded. *B*, 7075-T6 as-welded. *C*, 6061-T6 as-welded. *D*, ZK60A-T5 bend test. *E*, ZK60A-T5 to 7075-T6 as-welded. *F*, ZK60A-T5 flash removed. *G*, ZK60A-T5 to 7075-T6 after tensile test. Note fracture in ZK60A-T5

dence of the original interface is present, although in this case the fracture and necking occurred over an area of about $\frac{1}{4}$ in. in the weld zone. In some cases where fracture occurred away from the weld zone, in the base metal, higher elongations were obtained. Examples are a series of forge-welded test bars illustrated in Fig. 11. Top left is ZK60A-T5 (magnesium) as-welded. Center left is 7075-T6 (aluminum) as-welded, and bottom left is 6061-T6 (aluminum) as-welded with flash removed. This is one-half of a $\frac{3}{4}$- x 3-in. cross-section test bar. Top right is a bend test in a forge-welded ZK60A-T5 magnesium bar. Center right is a forge weld between 7075-T6 aluminum and ZK60A-T5 magnesium bar. Bottom right is a forge weld in ZK60A-T5 magnesium with weld flash removed. At the bottom is a fractured tensile bar of 7075-T6 aluminum, welded to ZK60A-T5 magnesium. Note fracture away from weld in the magnesium bar. The weld interface can easily be seen because of the greater stretching which has taken place in the magnesium bar.

Forge Welding of High-Strength Magnesium Alloys

Forge welding of magnesium alloys was limited to AZ31B-F and the previously unweldable ZK60A-T5 of nominal composition. Welding conditions for these magnesium alloys were similar to those used for the aluminum alloys, with the exception that somewhat higher temperatures were successfully used since it is possible to hold these alloys at a higher temperature for a longer period of time without any harmful effect on their room temperature properties. Table 5 shows the properties of forge welds in these two magnesium alloys. The samples were welded with a total upset pressure of 35 tons, with a total upset of material of 2 in. Heating and welding times were less than 30 sec, and the best preheats for welding AZ31B-F were in the range of 535 to 600° F while for ZK60A-T5, the best conditions were

Table 5—Forge-Weld Conditions and Properties of Joints in AZ31B-F and ZK60A-T5 $\frac{3}{4}$-in. Extruded Rod

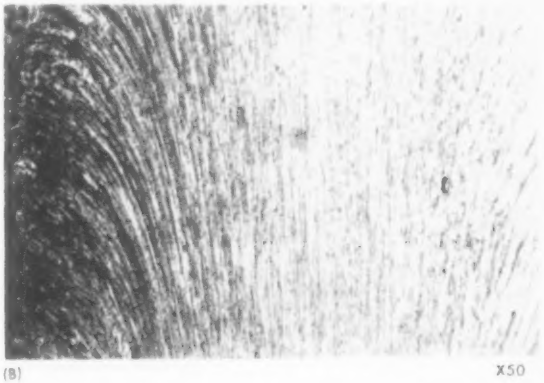
Temperature, ° F	*Time at temperature, sec*	*Ultimate tensile strength, psi*	*Yield strength, psi*	*Elongation in 2 in., %*	*Efficiency, %*
		AZ31B-F			
575	30	52,400	19,100	12.0	135
600	30	50,000	18,500	14.0	129
650	30	47,300	18,000	13.0	122
550	30	51,000	18,900	14.0	131
Base metal		38,800	31,000	15.0	
		ZK60A-T5			
600	20	50,000	32,600	9.0	101
500	20	51,700	32,800	14.0	105
450	18	48,900	29,900	11.0	99
415	15	49,600	29,100	11.0	100
450	15	50,200	29,800	10.0	101
Base metal		49,300	38,800	19.0	

(A) Acetic glycol etch X5

(B) 5% Nital etch X50

Fig. 12 Photographs of sections through a forge weld in magnesium alloy AZ31B-F. Note flow lines and sound metallurgical bond. (Reduced by 1/2 upon reproduction)

(A) X4



(B) X50

Fig. 13 Photograph of sections through a forge weld in magnesium alloy ZK60A-T5 showing flow lines and good metallurgical bond. Acetic glycol etch. (Reduced by 1/2 upon reproduction)

415 to 550 F for 15 to 25 sec. The welded bars were machined into standard 1/2-in. diam reduced-section tension bars. The unusual strengths of AZ31B-F welds were difficult to believe at first, but a recheck on the broken test bars indicated these were real. A plausible explanation for this effect was found in the works by Rappleyea, Perry and Ansel. It is shown that precompression loading beyond the yield strength resulted in a deformation mechanism such that preferred orientation occurred due to slip and twinning, and on reversal of the stress, lowered proportional limit and increased tensile strength resulted. Since fractures in the welded bars occurred in the base metal at some distance from the weld, the above reasoning appeared to explain the facts in this case. In ZK60A-T5 welds, the yield strengths were also reduced; but not to the same extent as in AZ31B-F, possibly because of the higher original yield strength in the base metal before stressing.

Examination of the welds under low and high power magnifications showed that good metallurgical bonds were present on all samples examined. Cross sections of these welds are shown in Figs. 12 and 13, showing soundness and flow lines due to upsetting.

Forge Welding High-Strength Aluminum Alloys to High-Strength Magnesium Alloys

A number of welds have been made between aluminum 6061-T6 and magnesium ZK60A-T5 alloys, and also, between 7075-T6 aluminum alloy and ZK60A-T5 magnesium alloy. Table 6 shows typical properties obtained from tensile tests of welds made between these alloy systems. As a result of this work, the first successful high-strength, ductile welds between aluminum

Table 6—Properties of Forge Welds Between Magnesium and Aluminum Alloys

Sample	*Ultimate tensile strength, psi*	*Yield strength, psi*	*Elongation in 2 in., %*	*Efficiency, %*
ZK60A-T5 to 6061-T6*	46,800	34,700	6.0	95
ZK60A-T5 to 6061-T6†	46,300	34,000	5.0	95
ZK60A-T5 to 7075-T6†	52,300	35,200	6.5	101
ZK60A-T5 to 7075-T6†	51,800	34,900	6.2	101

* Failed in weld.
† Failed in ZK60A.

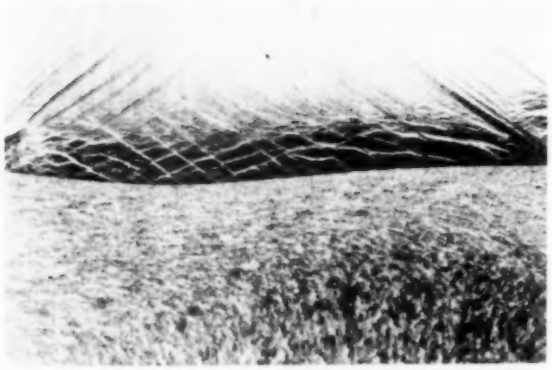


Fig. 14 Photomacrograph of forge weld between 6061-T6 aluminum alloy and ZK60A-T5 magnesium alloy. Note flow lines and cold work. 10% HF plus acetic picral etch. X8. (Reduced by $\frac{1}{2}$ upon reproduction)

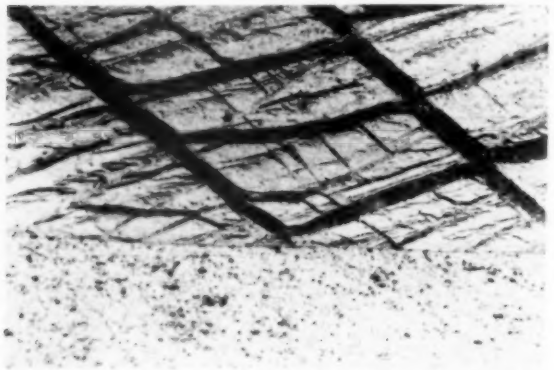


Fig. 15 Photomicrograph of forge weld between 6061-T6 aluminum alloy to ZK60A-T5 magnesium alloy showing metallurgical bond. Acetic picral etch. X100. (Reduced by $\frac{1}{2}$ upon reproduction)

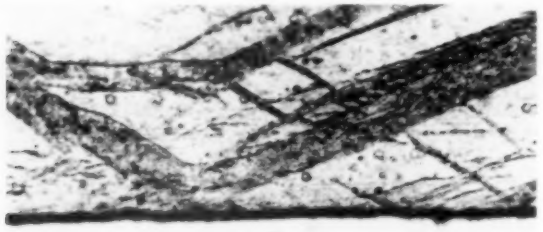


Fig. 16 Photomicrograph of forge weld between 6061-T6 aluminum alloy and ZK60A-T5 magnesium alloy showing metallurgical bond. Acetic picral etch. X300. (Reduced by $\frac{1}{2}$ upon reproduction)

and magnesium alloys have been made. It is particularly interesting to note that successful welds were made between the aluminum alloy and the magnesium alloy which are most difficult to weld.

Photomicrographs in Figs. 14, 15 and 16 illustrate the type of interface which has been obtained in welds between aluminum and magnesium alloys. The extremely-fine junction line showed good metallurgical bond and no visible evidence of brittle intermetallic compound normally associated with magnesium to aluminum welds was apparent. The high degree of upset which resulted in high plastic deformation is readily apparent by the lines of flow in the aluminum, and by the deformation of the magnesium alloy ZK60A-T5. In order to weld these two alloys successfully it was necessary to produce a suitable heat balance so that the flow characteristics of the two alloys being welded were similar. Thus, for forge welding it is generally desirable to have the higher-strength alloy at a higher temperature than that of the lower-strength alloy. These preliminary results indicate that other alloy combinations may be successfully forge welded where heat balances can be obtained to produce uniform flow conditions of the two components.

Theory of Forge Welding

When two clean metal surfaces are brought together, the metal atoms will be brought close enough together at the points of contact to cause mutual attraction and bonding. Such an interface can be considered as a grain boundary in which strong attractive forces are exerted despite the disorder present. Sticking or welding will be observed at the points of contact. Bowden and Young demonstrated this by cleaning iron, nickel and platinum *in vacuo* in attempting to find friction coefficients. They found that mere contact caused welding. Later Bowden and Rowe showed that in many cases the bonds so formed were weakened or broken by elastic stresses near the weld which appeared when the welding force or pressure was released. Maklin and Yankee showed that friction was largely due to solid phase bonding. They showed that by cleaning metallic surfaces and testing in inert atmospheres large increases in friction resulted. Determinations of friction under very light loads on copper and aluminum showed very low coefficients of friction. This was attributed to the fact that the oxide layer was not broken and that no welding could result.

All metal surfaces, no matter how smoothly polished, are irregular on an atomic scale. A ground, superfinished surface will have a peak to valley height averaging about 5×10^{-6} cm or about 200 atom layers. The projecting areas have commonly been termed asperities. When two surfaces are brought together, point contacts are formed. The pressures built up at these points of contact are very high. If they exceed the yield point, metal flow will result, causing an increase in bearing area. This flow will continue until the product of the yield strength and the area of contact equals the applied force. Thus, for any applied force, the approximate area of contact can be estimated. The mean pressure is given by $Pm = cY$ where "Y" is a "representative" yield strength of the asperities. This value will be influenced by work hardening. The factor "c" depends on the size and shape of the surface irregularities, but for conical and hemispherical shapes it has a value of about 3.

Complete contact over the interface will not be obtained until pressures equal to approximately three times the yield strength are provided over the whole area. In the theoretical case in which surfaces are absolutely clean, pressures applied to give 100% area of contact should provide 100% bond strength. However, if the deformation is done below the recrystallization temperature some areas (asperities) will be plastically deformed and upon release of the applied pressure, a residual tensile stress will be left in the other areas. These residual stresses will often cause the failure of a joint made with low deformations.

The photomicrographs of these pressure welds show severe cold work of the metal near the interface. The original metal grains have been distorted during welding and fragmented into sub-grains or crystallites wherein deformation occurred by dislocation, movement or slippage. These sub-grains are surrounded by envelopes of severely distorted "amorphous structure." The joint interface consists of an amorphous structure with intimate contact of the faying surfaces. For sound welds the surface preparation is very important since even a thin layer of grease or moisture on the faying surfacing will prevent bonding. After initial contact of these mating surfaces, the forging breaks up the brittle oxide layer and disperses adsorbed gases by "stretching" the interface. This is accomplished by correct die design and upset. For good aluminum and magnesium forge welds made below recrystallization temperatures, the final interfacial area should be two to four times the initial area of contact.

Once true metallic contact has been attained in the welding process, atoms from the faying surfaces approach to within interatomic distances of each other. Atomic attraction forces reach a maximum at interatomic distances of 2.86 Å for aluminum and 3.19 and 3.20 Å for magnesium. Actually the atoms have then approached close enough to permit continuous exchange of their free electrons, resulting in a lower and more stable energy state the so-called "metallic bond." This is all that is required for any welding process to obtain a good metallurgical bond, and is brought about in various ways for each welding process usually through melting. In forge welding this is accomplished in the solid state by pressure and plastic flow as discussed above.

In forge welding different metals together compatible crystal structures will aid bonding. Aluminum is face-centered cubic and can be bonded readily to copper (F.C.C.), gamma iron (F.C.C.), nickel (F.C.C.) and to magnesium (C.P.H.). Magnesium has a close packed hexagonal structure, but this structure is very similar to the face-centered cubic of aluminum since in each case adjacent layers of atoms have the same relative configuration and the same number of adjacent atoms (coordination number).

In all the above cases the atomic diameters are also within the 14% found necessary for solid solution of one metal in another.

General Characteristics of New Forge Welds in Aluminum and Magnesium Alloys

From the information obtained to date, it can safely be said that all aluminum- and magnesium-wrought alloys can be forge welded. Normally, butt joints are used; however, mitre joints can also be forge-butt welded. Because of the lower cost of equipment and current demand, forge welds do not have the limitations on size of components which can be bonded that are imposed on flash-butt welds. Thus, a wider range of sizes, thicknesses and alloys can be fabricated by forge-welding techniques. Unlike other welding processes, no cast metal exists in the weld area and no heat-affected zone is produced as a result of the welding operation. During the welding operation some warm and cold working occurs in the base metal and in the weld zone. While no extensive work has been done to date on the corrosion characteristics of the forge welds in aluminum or magnesium alloys, there is every reason to expect they will be equal to or superior to welds made by other methods—primarily because of the lack of the cast structure. A good uniform stress distribution is obtained and consequently superior performance in fatigue loading can be expected because of the lack of a cast metal zone. In cases where an anodic finish is required after welding, little or no color contrast at the joint interface is obtained.

Whereas the cost of the flash-butt welding machine for welding 7075-T6 aluminum alloy in a one-square-inch cross section would be about thirty to thirty-five thousand dollars, a forge-welding machine can be obtained for performing the same operation at less than one-half this cost. The cost of operation and upkeep of the equipment is much less, as little or no current is used in the welding process. The upset distance and spacing of the dies is about one to one and one-half times the wall thickness. Dies are made of ordinary mild steel with hard-face material at the die lip to reduce wear. The cost of dies for different shapes is approximately the same as that for flash-butt welding and will vary from about $300.00 to $2500.00, depending on the complexity of the shape.

Potential Applications and Significance of New Forge Welding

During the past twenty years, many of the welding processes essential to the nonferrous fabricating industry have been developed or perfected. The development, growth and utilization of many of these nonferrous metals, such as aluminum and magnesium, can to a large extent be directly attributed to the improvement and ease of fabrication made possible by the use of new welding processes. It is, therefore, an important and significant step forward when a process such as warm forge welding becomes available to perform operations that cannot be performed in any other way. This is particularly true when quality is improved, design is simplified and cost of existing products is reduced. It is reasonable to predict, therefore, that forge welding, and indeed the whole field of pressure welding of non-

ferrous alloys, will play a prominent role in product fabrication. During the course of the next ten years, forge welding will take its place beside resistance welding and inert-gas arc welding as one of the important methods for welding nonferrous metals, fabricating new products and improving the design of old products.

Some of the more obvious applications for which forge welding already appears to be not only feasible but also the best, and in some cases the only method of fabricating, are listed below:

(a) Large extruded panels for aircraft and transportation products. It is now entirely feasible to design extruded shapes of many kinds which can be welded together to develop large extruded panels in the highest-strength aluminum and magnesium alloys to obtain properties at the joint interface equivalent to those of the base metal. Thus, much wider panels can be made available and the cost of fabrication and waste of materials involved in present processes can be greatly reduced.

(b) Butt welding structural members. It is now possible to butt weld nonferrous alloys for structural applications such as the welding of extrusions to forgings, rolled bars and other wrought products to obtain high joint efficiency at the weld interface; thus, making it possible to simplify design, reduce weight and improve quality.

(c) Development of new products. Further modifications and development of the forge-welding process may prove invaluable in the production of such products as (1) tanks for hot water, acid, hydrogen peroxide, nitric acid and other chemicals; (2) truck and automotive rims; and (3) heat exchangers.

(d) Nuclear and missile applications. Forge welding may well prove a distinct advantage in the bonding of dissimilar materials for nuclear applications such as the welding of zirconium to steel and zirconium to aluminum. Forge welding may also be an important factor in the welding of many of the new metals which are now attracting interest, such as molybdenum, beryllium and titanium.

While some work has already been started on some of these new products, it is anticipated that much additional development work will be necessary before the full usefulness of this process is realized. Perhaps some of the most important early applications will be where the process is most needed for automotive rims, chemical tanks, armour plate and other military components.

Acknowledgment

The assistance and cooperation of numerous people and companies in obtaining data and encouragement in pursuing this program is gratefully acknowledged. Particularly, our thanks are extended to: Paul Klain, Dow Chemical Co., Midland, Mich.; Dr. R. S. Mateer, University of Pittsburgh; Dr. M. Prior, consultant; G. Hoglund, Aluminum Company of America; C. B. Smith, Douglas Aircraft Corp.; and G. W. Papen, Lockheed Aircraft Corp.

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MANIPULATOR FOR AUTOMATIC WELDING

Hinged rail on booms gives angular displacement for joints in tapered girders

BY HARRY S. POWELL

Automatic submerged-arc welding of flanges to webs on tapered girders up to around 30 ft in length requires some means for positioning either the work or the travel of the welding head so that the angle of the upper or tapered side can be traversed accurately. Custom-made welding manipulators are available for such work but are rather expensive and complicated in design. In considering the problem of building suitable equipment in our own structural shop, it was ultimately decided that a modified gantry-type manipulator would handle the job and could be assembled at moderate cost (see Figs. 1 and 4).

Such a machine differs from the conventional in that the rail carrying the welding head is not fixed to the end columns but is capable of lateral angular adjustment. This makes it possible to weld in one direction, then by pushbutton control to change the direction of the rail to angle in or out without having to move the work or to reset the speed of the head.

Among principal reasons dictating the choice, in addition to the foregoing, were: (1) versatility for a variety of structural welding on irregular shapes requiring long seams; (2) availability of materials such as WF beams, pipe, gusset plates, etc., always at hand in a structural shop; (3) minimum of machined parts, with no machining of ways or rails involved; and (4) adaptability of modified automotive parts and other standard components.

Reference to accompanying plan, elevation and end views will disclose the general arrangement and identification of the various components. Columns are 8-in. standard black pipe, set 20 ft apart. To them are welded 3 x 3 x $\frac{1}{2}$-in. angle rails on which boom saddles travel. These welds are intermittent, 4 in. long on 10-in. centers, the angles being diametrically opposite one another. Base of the column is welded to a 10-in. WF 45-lb beam, reinforced by a $\frac{3}{8}$-in. plate gusset. Tops of the columns are tied together by a similar size beam, mounting the mechanism to control vertical travel of the booms. Knee braces are provided at each end to insure rigidity.

Boom saddles are basically $\frac{3}{4}$-in. plate upon which are mounted the roller assemblies for vertical travel on the columns and for in-and-out movement of the booms. The latter are also of 8-in. pipe, with welded-on angle track rails for horizontal movement of the booms.

Harry S. Powell is Production Manager, Pittsburgh-Des Moines Steel Co., Fresno, Calif.

Story based on an award-winning paper submitted in the recent Machine Design Competition sponsored by the James F. Lincoln Arc Welding Foundation, Cleveland, Ohio.

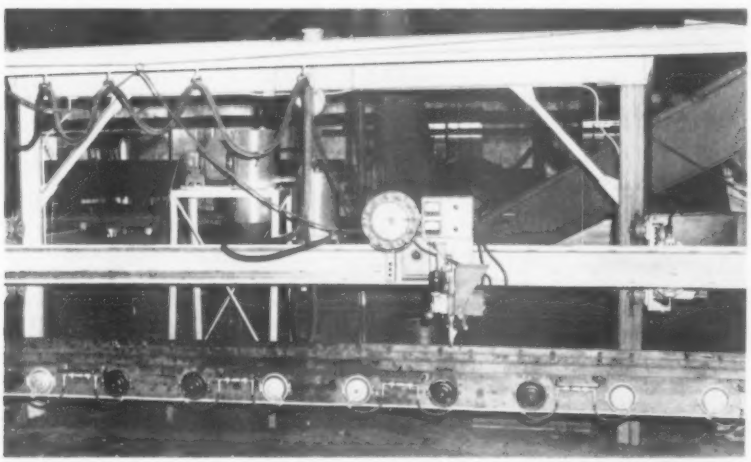

Fig. 1 Over-all view of modified gantry-type manipulator for automatic arc welding, showing welding carriage on 33-ft rail. Booms support the rail at either end and may be traversed in or out independently to give angular displacement of rail in welding such elements as tapered girders

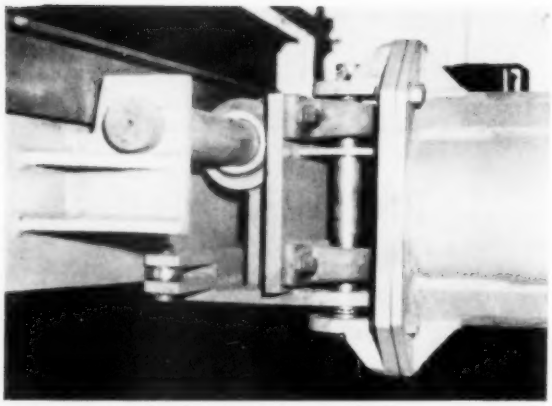

Fig. 2 Sliding hinge assembly is required on one boom to allow the rail to be moved in or out at a greater distance at one end than at the other. Rollers along the lower edge of the rail hold it squarely with the boom and hinge pin. Use of standard components cuts costs substantially

The roller assembly comprises essentially a 1948 model Buick front-wheel spindle which is turned and fitted or plug welded, so to speak, into a 6 x 6-in. plate. This small plate, in turn, is attached by cap screws to the large saddle plate. Three of the four roller assemblies on each side of the main saddle plate are adjustable for alignment purposes. Rollers are machined with a 90-deg groove to travel the angle-iron rails. On the opposite side of the saddle, four other rollers are positioned to accommodate the boom for lateral movement.

One end of the boom is fitted and welded to a mounting plate carrying a hinge-pin assembly which is attached to a standard rail assembly, 33 ft long, on which rides a standard submerged-arc welding head. The boom at either side may be traversed a total distance of 6 ft, thereby permitting the rail to be positioned at any angle from parallel to 25½ deg in or out at either end.

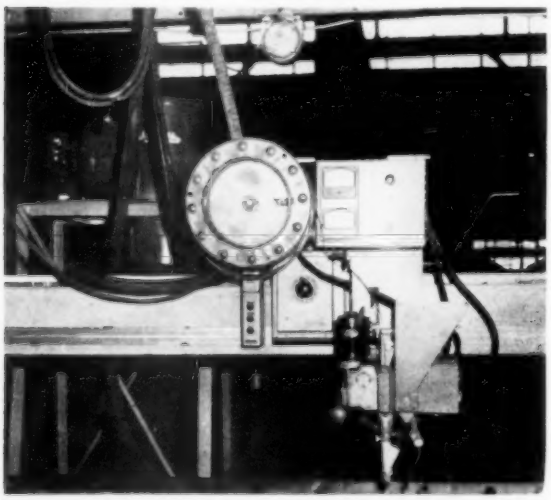

Fig. 3 Automatic welding head and controls travel along the rail to given maximum weld length of 31½ ft. Rail is of simple construction, with two channel sections welded together and cold-rolled flats intermittently welded to top and outer face for smooth travel of rollers on the carriage

The rail is built up from two lengths of 10-in., 15-lb channel, boxed and intermittently welded. Along the top is a $\frac{7}{8}$- x 4-in. cold-rolled flat bar and along the outer face is a $\frac{1}{2}$- x 2-in. flat bar, both these bars being fixed by $\frac{1}{4}$-in. fillet welds 2 in. long on 12-in. centers. These are to accommodate the rollers of the welding head, thereby eliminating all machining on the rail assembly. On the rear face are welded the hinge assemblies, on 20-ft centers to match the boom ends, and to them are attached 1½-in. pillow blocks to allow the rail to be angled. These blocks swing on 1½-in. diam shafts which are fixed to the booms.

The unique feature of the rail being able to move in or out at either side independently is possible only through incorporation of a sliding hinge at one end, a close-up of this mechanism being shown in the accompanying Fig. 2. It involves a Thompson ball "linear motion bearing" or bushing which permits the hinge assembly to slide on a shaft fixed parallel to the channel rail. Alignment is maintained by two small rollers bearing against the lower edge of the rail.

Vertical travel of the booms is accomplished through chain and sprocket drives, powered by a ½-hp motor anchored to the top cross beam and driving two shafts through gear-reduction unit. Maximum vertical travel of about 8 ft is possible, at a speed of about 25 ipm. With both shafts coupled to a common gearbox and having lift sprocket chains of exactly the same length, each saddle will travel up or down uniformly, thus maintaining a horizontal rail at all times.

Side booms have independent drivers for lateral movement, using ¼-hp motors and belt-driven gear-reduction systems to give lateral boom speed of about 60 ipm. This means that three motors control vertical and lateral travel of the booms. They are actuated by pushbuttons on a pendant control box which also incorporates the standard carriage controls for the welding head (see Fig 3).

The machine location was arranged at the start so that the jig fixture holding the work could travel on cars past the welding station. These cars were to be set on 90 ft of rail—30 ft ahead of the machine for assembling the work into the fixture, 30 ft at the welding station and 30 ft beyond that point for unloading purposes. Modification of this layout was made later.

A 750-amp d-c generator was placed slightly to the rear of the left column when facing the machine. The lead was hung on a trolley to follow the welding carriage anywhere within an area of 7 x 35 ft. A flux-recovery unit was placed centrally and to the rear of the columns, as illustrated, to cover the same area as the welding carriage.

In a preliminary test run on a tapered girder, the lower chord flange was welded by means of the "fillet lap jaw" attachment on the welding head, and the girder then immediately turned over to the opposite side of the same flange for welding, so that distortion would be

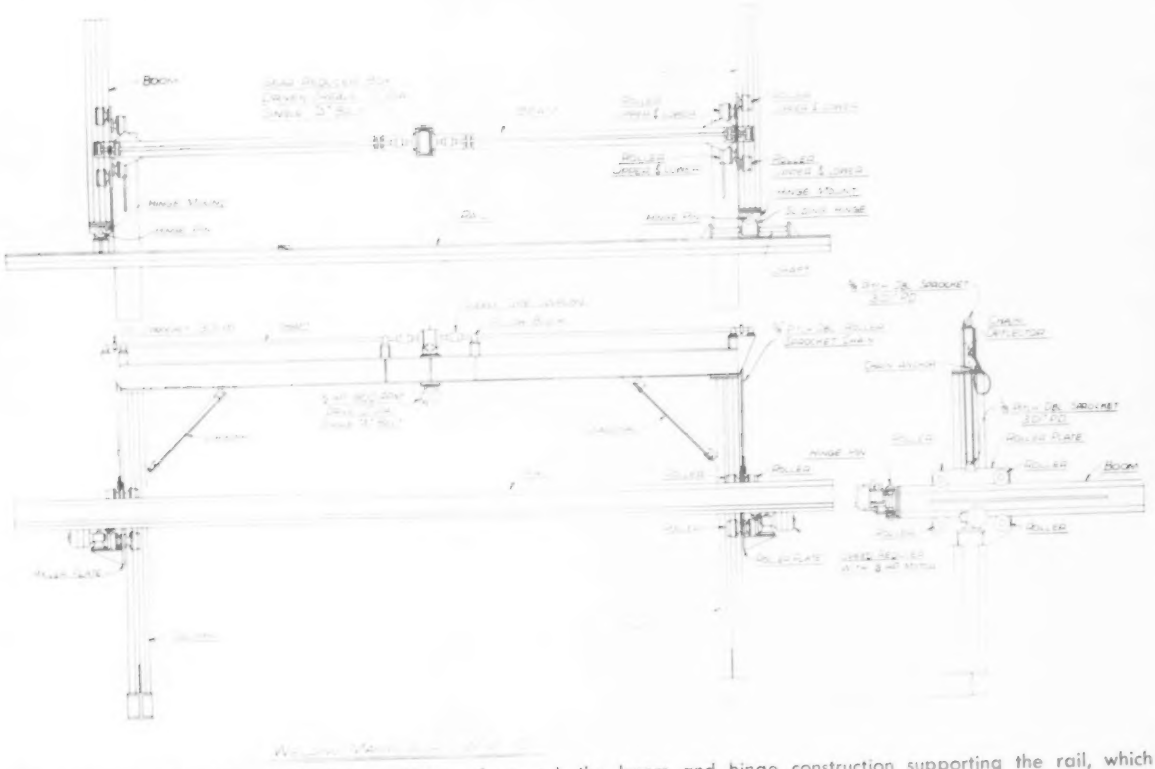

Fig. 4 Details of welding manipulator. Unique feature is the boom and hinge construction supporting the rail, which allows the rail to be displaced at an angle of as much as 25½ deg in either direction

avoided. It was, of course, unnecessary to line up the girder carefully to the machine, since the rail can be quickly lined up with the work by virtue of the angular displacement feature. After welding the joints along the lower chord, the rail was angled to the exact taper of the upper chord and that joint completed. Finally, the girder was turned over again, the rail angled in the opposite direction and the final weld pass made.

One unusual production contract involved the fabrication of box section rafters for a school building. They comprised two sections of 10-in. channel, with welds along the mating flanges. Before development of the manipulator, shop card cost ran to something over $8000 on the complete welding job. In the revised setup, a fixture was designed to clamp the two channels together, eliminating the need for tack welding. Briefly, it comprised two WF beams 30 ft long and parallel to each other 12 in. apart. At each end a hub was welded in place to permit rotating the assembly.

In one beam, at 24 in. intervals, were located twelve 9-in. air brake cylinders, as shown in one of the illustrations. They were connected to a common manifold to give a maximum combined squeezing force of 36,000 psi. Directly below this fixture were placed two 12-lb rails and a small rail truck permitting the welded box section to be slid out of the way.

Channels to be welded were simply dropped into the fixture against stops, air pressure applied to force them together tightly and a continuous bead run for the entire length of the joint. Then the fixture was rotated 180 deg and the opposite side welded similarly. A cost check on the improved job setup showed a saving of about $550 over the former $8000.

As to the machine cost itself, preliminary estimates were met quite closely in the finished unit. Total cost, including materials, parts, motors, machine work, wiring, outside subcontracting and welding generator, amounted to about $4600.

HARD SURFACING ELIMINATES UNNECESSARY REPLACEMENT COSTS

Oxyacetylene hard surfacing adds years of life to disks and seat rings in natural gas, crude oil and refined product pipe-line valves. Hard-surfaced disks and seat rings have been used for 18 years along a branch of the Service Pipeline in the Rocky Mountain area, yet none have been replaced.

These parts work in contact with each other, helping to regulate the flow of fluids at pressures up to 1800 lb per sq in. (see Fig. 1). They must resist corrosion and abrasion to insure the dependable opening and closing of the valves. For the past 21 years, the Walworth Co. at its East St. Louis, Ill. works has relied on hard surfacing to protect the seating surfaces of disks and seat rings.

Hard surfacing of these parts starts with grooving of surface areas to remove all scale, rust or other foreign matter. Corners and edges of the grooves are well rounded to assure even heating and better bonding between base metal and hard-surfacing deposit. Boric acid is painted on the work area to prevent scaling during preheating and to maintain the clean condition of the surface. Preheating to 900° F in a furnace is necessary to prevent cracking when hard surfacing.

After heating, two welding operators deposit a $^{3}/_{16}$-in. thick layer of $^{3}/_{8}$-in. hard-surfacing rod on the seating surfaces of each disk and seat ring of the valves, completing the job in 10 min (see Fig. 2). Then the hard-surfaced part is again placed in the furnace and brought back to preheat temperature. Slow cooling keeps distortion to a minimum. Grinding machines are used to finish finely the hard-surfaced surfaces (see Fig. 3).

Based on a story by the Linde Co., New York, N. Y.

Fig. 1 More than 70 valves regulate the flow of crude oil through this distribution manifold

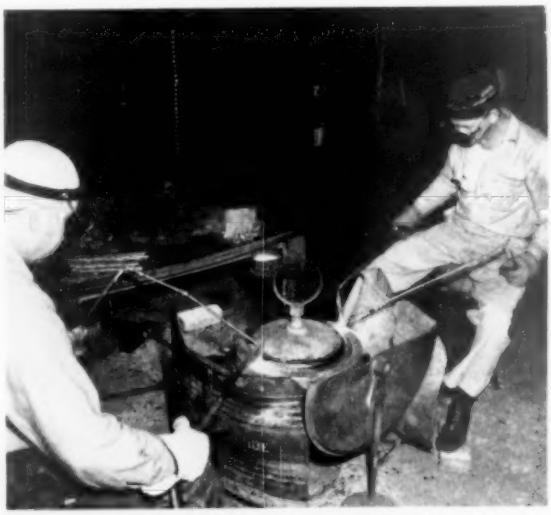

Fig. 2 Two welding operators hard surface the disk seating surface of a large pipe-line valve

Fig. 3 After hard surfacing, the surface of a seat ring is precision ground

BIG DIVIDENDS . . . WITH SPOT-WELDED REFRIGERATORS

By eliminating three costly fabrication steps, metal-arc spot welding has boosted production of refrigerator frames by 350%, at Koch Refrigerators, Inc., Kansas City, Kans.

Two types of units are metal-arc spot-welded: multi-deck market merchandisers and an award-winning line of commercial reach-in refrigerators.

Shells of the cabinets were previously fastened with a costly and time-consuming metal-screw method which required: (1) punched and dimpled holes, (2) insertion of the metal screws and (3) vapor sealing of the protruding screws. Metal-arc spot welding has eliminated all three steps . . . and produced more-rigid refrigerator frames in the bargain.

With the former method, two men were able to produce only seven refrigerator frames per day. With metal-arc spot welding, one man produces 12 frames a day.

Shells are formed from stainless-steel sheets which are lap spot welded to galvanized-steel sheets. Steel sheets used are of 14-, 16-, 18- and 20-ga thicknesses. The metal-arc spot welds can be made from any position and require access to the joint on one side only (Figs. 1, 2 and 3).

Based on a story by the Linde Co., New York, N. Y.

Fig. 1 Employing a metal-arc spot-welding machine, an operator welds a support to a refrigerator frame

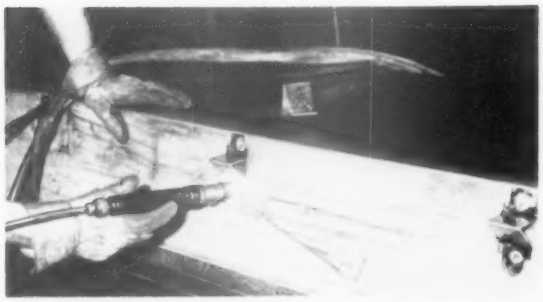

Fig. 2 An operator fastens a bracket to the side of a refrigerator frame. Note the clean, high-quality spot weld on the top part of the bracket

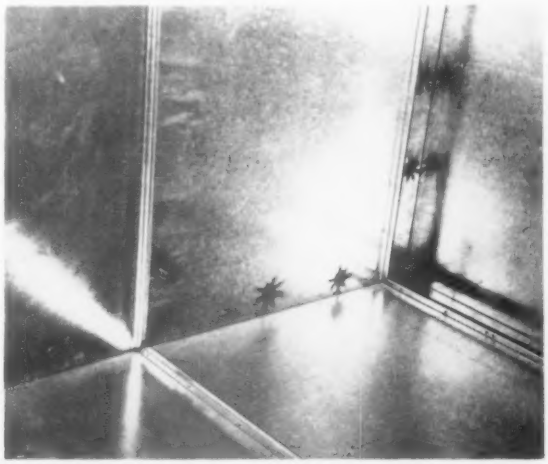

Fig. 3 Interior view of a completed refrigerator frame after it has been fabricated

Metal-arc spot welding makes an inexpensive job out of an especially costly one—assembling parts of a frame, as shown in Fig. 1, in which the weld has to go through 16-ga black iron, 20-ga galvanized steel and 16-ga creosote-coated channel iron.

To produce corrosion-resistant spot welds at a cost of a fraction of a cent per weld, Koch uses ECu coiled wire, $\frac{1}{16}$-in. diam. The operation is argon-shielded, at a flow of 25 cu ft per hr, to prevent atmospheric contamination of the weld zone. Normal welding time is less than one second per spot weld.

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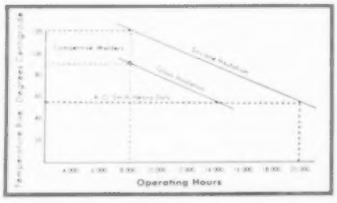

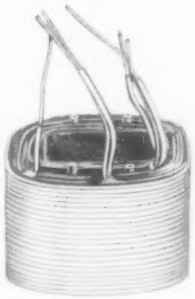

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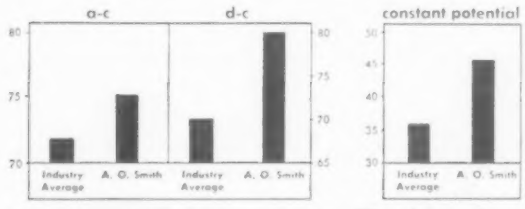

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Society News

St. Louis Prepared for AWS 1958 Annual Spring Meeting and Welding Show

A two and one-half million dollar display will be unveiled at St. Louis in mid-April when the annual Welding Show opens its doors for a three-day run at Kiel Auditorium.

Record-breaking in every sense of the word, the show will have the largest assembly of welding equipment, products and accessories ever gathered under one roof. It is estimated that over 3000 products will be on demonstration in the booths.

St. Louis, which never has been the site of any exposition which emphasized welding either directly or indirectly, is girding itself for a week of unprecedented activities which will cover every aspect of the welding art.

The technical aspect will be covered in the week-long Annual Spring Meeting at the Hotel Statler; the practical working aspect in a special welding conference at Kiel Auditorium; the displays and exhibits will give a three-dimensional quality to the lectures and papers; students will find educational lectures of special interest; plant tours will provide first-hand operational techniques; and a series of social events will highlight the good-fellowship aspects of the sessions.

Bennett Cerf, famed raconteur, TV star, publisher, author and columnist, will be the star of a banquet staged by the St. Louis Section, while all the officials of the AMERICAN WELDING SOCIETY will be on hand in the reception line at the annual President's Reception.

The annual meeting of the SOCIETY will open the proceedings on Monday, April 14th and will be followed by the delivery of the Adams Lecture by Ernest F. Nippes, of Rensselaer Polytechnic Institute, on "The Weld Heat-Affected Zone," and the opening of the week-long Annual Spring Meeting.

On Tuesday, the traditional chain cutting will open the doors to the Welding Show where over 1000 manufacturers' representatives will be on hand to answer visitors' questions. This gathering of the most expert knowledge of the industry is one of the most significant facets of the show. A visitor will find it possible to obtain almost any type of information about equipment and methods—new or old—in the shortest possible time.

Ninety-five authors, drawn from 15 states and Canada, will read papers during the technical sessions. In all, 63 papers will be presented in 21 sessions. The Metals Engineering Division of the American Society of Mechanical Engineers will co-sponsor four of the sessions.

Plant visits will include the factories of the A. O. Smith Corp. in Granite City, Ill., and the Midwest Piping Co., in St. Louis.

Many exhibitors will conduct hospitality suites in hotels for the further entertainment of visitors, and a four-day Ladies' Program has been arranged by the St. Louis Section.

Visitors who have not yet made their hotel reservations are urged to do so at once by writing the housing bureau at SOCIETY headquarters.

AWS DIRECTORS-AT-LARGE

Term Expires	1958	1959	1960
	F. H. Dill	J. H. Blankenbuehler	J. F. Deffenbaugh
	E. D. Peters	G. E. Linnert	A. E. Pearson
	J. L. Wilson	P. G. Parks	C M Styer
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APRIL 15-16-17, '58
KIEL AUDITORIUM
St. Louis, Missouri

TECHNICAL PAPERS SESSIONS

1958

AWS ANNUAL SPRING MEETING and ASME METALS ENGINEERING DIVISION CONFERENCE

APRIL 14–18 • HOTEL STATLER, ST. LOUIS, MO.

REGISTRATION
HOTEL STATLER

Sunday, April 13
3:00 P.M. to 6:00 P.M.
Monday, April 14
8:00 A.M. to 3:00 P.M.
Tuesday, April 15
8:00 A.M. to 4:00 P.M.
Wednesday, April 16
8:30 A.M. to 4:00 P.M.
Thursday, April 17
8:30 A.M. to 1:00 P.M.
Friday, April 18
8:30 A.M. to 12:30 P.M.

APRIL 14, MONDAY MORNING

Grand Ballroom

10:00 A.M.—Official Opening & Business Session
Chairman—*J. E. Dalo, Linde Company*
Address—*C. P. Sander, AWS President*
Annual Business Meeting
Induction of Officers
National Awards
Adams Lecture—*The Weld Heat-Affected Zone*
by Ernest F. Nippes, Rensselaer Polytechnic Institute

APRIL 14, MONDAY AFTERNOON—THREE SIMULTANEOUS SESSIONS—2:00 P.M.

1. Steel Weldability and Research

Grand Ballroom

Chairman—O. B. CARPENTER
Babcock and Wilcox Co.

Co-Chairman—M. F. COUCH
Bethlehem Steel Co.

A. The Effects of Porosity on Mild-Steel Welds

by William L. Green, M. F. Hamad and Roy B. McCauley, Ohio State University

B. Effects of Steel-Making Practice on Submerged-Arc Weld Porosity

by James T. Lapsley, Jr., University of California, Berkeley

C. A Study of Factors Affecting the Strength and Ductility of Weld Metal

by C. Marvin Wayman, University of Illinois, and Robert D. Stout, Lehigh University

2. Designing for Welding

Missouri Room

Chairman—T. J. CRAWFORD
Consulting Engineer

Co-Chairman—P. C. ARNOLD
Chicago Bridge & Iron Co.

A. Elements of Joint Design for Welding

by Kenneth H. Koopman, Knolls Atomic Power Lab., General Electric Co.

B. A Simplified Approach to Determining Stresses and Selecting Sections

by Omer Blodgett, The Lincoln Electric Co.

C. Product Design for Application to Welding

by John Mikulak, Worthington Corp.

3. Welding Arcs and Heat Flow

St. Louis Room

Chairman—J. H. BLANKENBUEHLER
Hobart Brothers Co.

Co-Chairman—R. M. GAGE
Linde Company

A. Some Practical Limitations of High-Current Welding Arcs

by A. Lesnewich, Air Reduction Research Laboratory

B. Plasma Energy Transfer in Gas-Shielded Welding Arcs

by H. C. Ludwig, Westinghouse Research Laboratories

C. Cooling Rates and Peak Temperatures in Fusion Welding

by Clyde M. Adams, Jr., Massachusetts Institute of Technology

APRIL 15, TUESDAY MORNING—THREE SIMULTANEOUS SESSIONS—9:30 A.M.

4. Strength of Welds

Grand Ballroom

Chairman—C. E. Bowman
University of Illinois

Co-Chairman—E. A. Kerby
Midwest Piping Co.

This session is sponsored by the ASME Metals Engineering Division

A. Co-operative Investigation of a New Welding Electrode for Stainless Steels

by R. D. Wylie, The Babcock & Wilcox Co.

B. Welding Metallurgy of Cr-Mo-V Steels for High-Temperature Steam Turbine Components

by R. J. Christoffel, R. M. Curran, F. H. Domina and C. H. Soldan, General Electric Co.

C. Welding Qualifications and Component Performance

by W. L. Fleischmann, Knolls Atomic Power Laboratory, General Electric Co.

5. Resistance Welding

St. Louis Room

Chairman—J. J. McKinney
The Budd Co.

Co-Chairman—K. M. Spicer
International Nickel Co.

A. Spot Welding of Inconel X in Thickness Range of 0.032 to 0.188

by Jean F. Harris, J. J. Riley, The Taylor Winfield Corp., and M. D. Bellware, International Nickel Co.

B. Spot Welding of Ti-6Al-4V Alloy

by Robert K. Nolen, John F. Rudy and Harry Schwartzbart, Armour Research Foundation, and H. D. Kessler, Titanium Metals Corporation of America

C. Evaluation of Spot Welds Made Through Primers and Sealers

by B. A. Schero, Detroit Arsenal

6. Aluminum and Magnesium

Rooms 202–204

Chairman—F. B. Baysinger
Kaiser Aluminum & Chemical Corp.

Co-Chairman—T. J. McElrath
Linde Company

A. Porosity in Aluminum-Alloy Welds

by Fred B. Collins, Alcoa Research Laboratories

B. New Forge Welding of Aluminum and Magnesium Alloys

by Lloyd A. Cook and Donald G. Shafer, Ravens Metal Products, Inc.

C. The Arc Welding of Wrought Magnesium-Thorium Alloys

by Paul Klain and L. F. Lockwood, The Dow Chemical Co.

APRIL 15, TUESDAY AFTERNOON—THREE SIMULTANEOUS SESSIONS—2:00 P.M.

7. Mating of Structural Properties with Design

Grand Ballroom

Chairman—W. E. Cooper
General Electric Co.

Co-Chairman—
William Burggrave
Monsanto Chemical Co.

This session is sponsored by the ASME Metals Engineering Division

A. Design Values for Thermal Stress in Ductile Materials

by B. F. Langer, Westinghouse Electric Corp.

B. Design of Thin-Walled Pressure Vessels Based Upon the Plastic Range

by Joseph Marin and M. G. Sharma, Pennsylvania State University

C. Ductility and Energy Relations in Charpy Tests of Structural Steels

by J. H. Gross and R. D. Stout, Lehigh University

8. Resistance Welding

St. Louis Room

Chairman—T. E. Jones
Precision Welder & Flexopress Corp.

Co-Chairman—C. E. Pelg
American Motors Corp.

A. An Investigation of Lap Seam Welds in 17-7PH Stainless Steel

by E. J. Funk and A. C. Willis, Temco Aircraft Corp.

B. Seam Welding Galvanized Steel

by William J. Allen, Shell Development Co. and M. L. Begeman, The University of Texas

C. Frequency Converter Welding Control Using Counting Tubes

by L. R. Broniak and W. A. Chaisson, Weltronic Company

9. Titanium

Missouri Room

Chairman—I. A. Oehler
American Welding & Mfg. Co.

Co-Chairman—C. E. Hartbower
Watertown Arsenal Labs.

A. Fusion Welding of Titanium in Jet-Engine Applications

by H. W. Hoefer, Orenda Engines, Ltd.

B. Inert-Gas Welding of Titanium for Nuclear and Chemical Application

by G. M. Adamson, Jr., and W. J. Leonard, Union Carbide Nuclear Co.

C. Development of Titanium-Clad Steel Using a Vacuum-Brazing Process

by Domenic A. Canonico and Harry Schwartzbart, Armour Research Foundation

APRIL 16, WEDNESDAY MORNING—THREE SIMULTANEOUS SESSIONS—9:30 A.M.

10. Design and Material for Low-Temperature Application

Grand Ballroom

Chairman—M. E. SHANK
Massachusetts Institute of Technology

Co-Chairman—RALPH CRISTIAN
Nooter Corp.

This session is sponsored by the ASME Metals Engineering Division

A. The Effect of Heat Treatment on the Microstructure and Low-Temperature Properties of Pressure-Vessel Steels

by J. H. Gross, E. H. Kottcamp and R. D. Stout, Lehigh University

B. Some Results of Fatigue and Welding Tests of 9 Percent Nickel Steel Plate

by T. N. Armstrong, International Nickel Co., and J. H. Gross, Lehigh University

C. Pressure Equipment for Low-Temperature Service

by C. R. Soderberg, Jr., M. W. Kellogg Co.

11. Brazing

St. Louis Room

Chairman—F. W. HUSSEY
Frankford Arsenal

Co-Chairman—A. S. CROSS
American Platinum Works Co.

A. Proposed Procedure for Testing Shear Strength of Brazed Joints

by Forbes M. Miller and Robert L. Peaslee, Wall Colmonoy Corp.

B. Diffusion Bonding Below 1000° F

by J. T. Niemann, R. P. Sopher and P. J. Rieppel, Battelle Memorial Institute

C. Bonding of Cermet Valve Components to Metals

by Gerald M. Slaughter, P. Patriarca and W. D. Manly, Oak Ridge National Laboratory

12. Uranium, Titanium and High-Nickel Alloys

Missouri Room

Chairman—P. G. PARKS
Solar Aircraft Company

Co-Chairman—E. IVERSON
Alloy Rods Co.

A. Submerged-Arc Welding of Uranium

by Gale S. Hanks, J. M. Taub and E. L. Brandige, University of California

B. Cracking Associated with Porosity in Titanium Welds Over 0.125 in. Thick

by Robert P. Olsen and James Gates, North American Aviation Co.

C. Control of Porosity in High-Nickel Alloy Welds

by George B. Pease, Robert E. Brien and Pierre E. LeGrand, International Nickel Co.

APRIL 16, WEDNESDAY AFTERNOON—THREE SIMULTANEOUS SESSIONS—2:00 P.M.

13. Steel Weldability and Research

Kiel Auditorium—Assembly Hall No. 1

Chairman—A. MULLER
Air Reduction Sales Co.

Co-Chairman—L. J. MCGEADY
Lafayette College

A. Evaluation of Weld-Joint Flaws as Reinitiating Points of Brittle Fracture—Part II

by Raeman P. Sopher, Perry J. Rieppel, David C. Martin, Battelle Memorial Institute, and Arthur L. Lowe, Jr., The Babcock and Wilcox Co.

B. Dynamic Measurement of Stress Associated with Weld Cracking

by William G. Moffatt, Sheldon S. White and Clyde M. Adams, Jr., Massachusetts Institute of Technology

C. Energy Absorption Studies of Welds in Tempered Martensitic Base Metal

by W. H. Bruckner, University of Illinois, and C. A. Robertson, Sun Oil Co.

14. Brazing

Kiel Auditorium—Assembly Hall No. 2

Chairman—B. RONAY
Consultant

Co-Chairman—G. A. FISHER
International Nickel Co., Inc.

A. The Metallurgy of Bonding in Brazed Joints

by Nikolajs Bredzs, Armour Research Foundation

B. Fundamentals of Brazing for Elevated-Temperature Service

by M. D. Bellware, International Nickel Co.

C. High-Temperature Vacuum Brazing of Jet-Engine Materials

by Ernst G. Huschke, Jr., and George S. Hoppin III, General Electric Co.

15. Welded Structures

Kiel Auditorium—Assembly Hall No. 3

Chairman—F. H. DILL
American Bridge

Co-Chairman—C. D. JENSEN
Lehigh University

A. The Design and Fabrication by Welding of the Carquinez Strait Bridge

by Leonard C. Hollister, California Division of Highways

B. Engineering Problems of an All-Welded Two-Way Truss System

by Wayne Teng, J. A. Sbarounis, Skidmore, Owens & Merrill and M. P. Gaus, University of Illinois

C. Behavior of Welded Corner Connections

by John W. Fisher, George C. Driscoll, Jr., Lehigh University, and F. W. Schutz Georgia Institute of Technology

APRIL 17, THURSDAY MORNING—THREE SIMULTANEOUS SESSIONS—9:30 A.M.

16. Casting Weldments

Grand Ballroom

Chairman—SIDNEY LOW
Chapman Valve Mfg. Co.

Co-Chairman—CARL RULFS
Union Electric Co.

This session is sponsored by the ASME Metals Engineering Division

A. Casting Weldments in a Petroleum Refinery

by Jay Bland, C. B. Parrish and R. C. Wheeler, Standard Oil Co.

B. The Welding of Low-Alloy Steel Castings Designed for High-Temperature, High-Pressure Service

by N. A. Chapin, C. H. Soldan and L. W. Songer, General Electric Co.

C. Welding Cast Components for Nuclear Power Application

by W. H. Rice, Electric Steel Foundry Co.

17. Steel Weldability and Research

Missouri Room

Chairman—DAVID SWAN
Linde Company

Co-Chairman—L. C. BIBBER
U. S. Steel Corp.

A. A Theory for Preheating of Plain, Low-Carbon Steels

by E. Paul DeGarmo, University of California, Berkeley

B. Temperatures for Rapid Uniaxial Stress Relief of Stainless Steels

by Howard S. Avery, American Brake Shoe Co.

C. A Quantitative Evaluation of Residual-Stress Relief in Pipe Weldments

by Jack E. Cook, General Motors Institute, and Roy B. McCauley, Ohio State University

18. Gas-Shielded Welding

St. Louis Room

Chairman—F. H. COX
National Cylinder Gas Co.

Co-Chairman—J. W. KEHOE
Westinghouse Electric Corp.

A. Industrial Applications of Magnetic-Flux Gas-Shielded Arc Welding

by R. T. Telford and F. T. Stanchus, Linde Co.

B. Controlled-Atmosphere Arc Welding

by Norman E. Weare and Robert E. Monroe, Battelle Memorial Institute

C. Tungsten-Arc Welding of 0.002 and 0.005-in. Stainless Steel and Titanium

by J. C. Collins and S. P. Jenkins, Sr., Convair

APRIL 18, FRIDAY MORNING—THREE SIMULTANEOUS SESSIONS—9:30 A.M.

19. Submerged-Arc Welding

Grand Ballroom

Chairman—A. G. HOGABOOM
Bethlehem Steel Co.

Co-Chairman—J. HEADAPOHL
Hobart Brothers Co.

A. Welding Alloy Steels Under Bonded Fluxes

by Hallock C. Campbell and Wallace C. Johnson, Arcos Corp.

B. Submerged-Arc Alloying for Maintenance and Fabrication

by Robert A. Wilson, The Lincoln Electric Co.

C. Submerged-Arc Applications in the Fabrication of Railroad-Car Components

by Charles A. Zwissler, Kaiser Steel Corp., and Robert A. Hay, Linde Co.

20. Application, Equipment and Inspection

Missouri Room

Chairman—JAY BLAND
Standard Oil Co.

Co-Chairman—B. J. BRUGGE
Lincoln Electric Co.

A. Automatic Welding of Aircraft Accessory Turbine Wheels

by Allan J. Rosenberg and Ernest W. Jamison, General Electric Co.

B. Aluminum Welding Cable

by John G. Stone, Kaiser Aluminum & Chemical Corp.

C. Use of Radioactive Welding Wire for Nondestructive Inspection of Welds

by Paul T. Barnes, U. S. Naval Ordnance Test Station, and Gordon L. Locher, Western Radiation Laboratory

21. Gas-Shielded Welding

St. Louis Room

Chairman—G. ROTHSCHILD
Air Reduction Sales Co.

Co-Chairman—RALPH CHRISTIAN
Nooter Corp.

A. Inert-Gas-Shielded Consumable-Electrode Welding of Molybdenum

by Norman E. Weare, Robert E. Monroe and David C. Martin, Battelle Memorial Institute

B. Inert-Gas-Shielded Arc Welding of Silicon and Aluminum Bronzes

by Paul L. Hemmes, Revere Copper and Brass Inc.

C. Effect of Welding Speed on Strength of 6061-T4 Aluminum Joints

by William L. Burch, Bell Aircraft Corp.

EDUCATIONAL LECTURE SERIES

Dallas and Los Angeles Rooms

MONDAY, APRIL 14, 4:30 TO 6:00 P. M.

TUESDAY, APRIL 15, 4:30 TO 6:00 P.M.

Chairman—CLARENCE E. JACKSON, Linde Company

Co-Chairman—T. EMBURY JONES, Precision Welder & Flexopress Corp.

Engineering Behavior of Welded Structures

by Earl R. Parker, University of California

OTHER ACTIVITIES

APRIL 14, MONDAY

6:00 P.M.—President's Reception in Foyers 1, 2 and 3, Hotel Statler

8:00 P.M.— Annual Dinner in Grand Ballroom of Hotel Statler

APRIL 15, TUESDAY

9:00 A.M.—Educational Activities Committee Meeting in Room 218 of Hotel Statler

12:30 P.M.—RWMA Luncheon Meeting in New York Room

2:00 P.M.—National Membership Committee Meeting in Cleveland Room

7:00 P.M.—Ohio State University Student Alumni Dinner in New York Room

APRIL 16, WEDNESDAY

10:00 A.M.—Manufacturers Committee Meeting in New York Room of Hotel Statler

2:00 P.M.—Open Meeting of National Nominating Committee in New York Room

4:30 P.M.—Section Officers Meeting in Rooms 202–204

6:00 P.M.—WRC Dinner in Los Angeles Room

8:00 P.M.—WRC Meeting in Dallas Room

APRIL 17, THURSDAY

10:00 A.M.—Board of Directors Meeting in New York Room of Hotel Statler

12:00 Noon—Sustaining Member and Board of Directors Luncheon Meeting in Rooms 202–204–206

INFORMAL PANEL DISCUSSIONS

KIEL AUDITORIUM *Assembly Hall No. 1*

TUESDAY, APRIL 15 2:00 P.M.

Panel Session on Practical Shop Operations

Chairman: T. B. Jefferson, Welding Engineer

PLANT TOURS

● **Wednesday, April 16**—Tour of A. O. Smith Corp. plant in Granite City, Ill., where automobile bodies are fabricated. This tour will have special interest because visitors here will see for the first time the mass production assembly line of the all-welded 1958 model Chevrolet automobile body frame.

● **Thursday, April 17**—Tour of the Midwest Piping Co. which is a leading prefabricator of welded power-plant piping and pipe fittings. Interesting examples of modern welding procedures will be shown. En route from the plant, there will be a stop at Anheuser-Busch, where a tour of the plant facilities will be made.

Each tour is a morning tour.

LADIES' PROGRAM

MONDAY, APRIL 14

8:30 A.M.–4:00 P.M.	Registration in Daniel Boone Room of the Statler Hotel.
9:00 A.M.	Coffee Hour in Daniel Boone Room.
11:30 A.M.	Luncheon in the Tea Room, sixth floor of Stix-Baer & Fuller Department Store.
1:30 P.M.	Afternoon tea and bridge party in the Daniel Boone Room.
6:00 P.M.	President's Reception in Foyers One, Two and Three on sixteenth floor of Statler Hotel.
8:00 P.M.	Banquet in Grand Ballroom, sixteenth floor of Statler Hotel.

TUESDAY, APRIL 15

8:30 A.M.–4:00 P.M.	Registration in Daniel Boone Room.
9:00 A.M.	Coffee Hour in Daniel Boone Room.
11:30 A.M.	Buses leave hotel for Frontier Room.
12:00 Noon	Cocktail and Luncheon in St. Louis' famous Frontier Room of the Montclair.
2:15 P.M.	Buses leave the Frontier Room to return to the hotel via Maryland Avenue and the Midtown theater area. Others may wish to leave the buses to shop or attend a matinee at one of the Midtown theaters. Those not leaving buses will be returned to the Statler Hotel arriving about 3:00 P.M.

WEDNESDAY, APRIL 16

8:30 A.M.–4:00 P.M.	Registration in Daniel Boone Room.
9:00 A.M.	Coffee Hour in Daniel Boone Room.
10:00 A.M.	Buses leave hotel for conducted tour of the St. Louis City Art Museum, with time for browsing before lunch.
12:00 Noon	Luncheon will be served in the Indian Gallery of the new Art Museum Restaurant.
1:30 P.M.	Board buses to resume tour.
1:45 P.M.	Visit to the beautiful Jewel Box Floral display in Forest Park.
2:30 P.M.	Board buses for return to hotel.
3:00 P.M.	Arrive at Statler Hotel.

THURSDAY, APRIL 17

8:30 A.M.–4:00 P.M.	Registration in Daniel Boone Room.
9:00 A.M.	Coffee Hour in Daniel Boone Room.
10:00 A.M.	Buses leave hotel for a conducted tour of St. Louis' Plaza area—the levee and riverfront—the Old Cathedral (oldest west of the Mississippi)—the picturesque Soulard Market—the old German section of the city—a visit to Shaw's Gardens—luncheon at Stan Musial's & Biggie's Restaurant—and then to historical Grant's Farm for a tour of August Busch's beautiful baronial estate, home of the Budweiser Clydesdales and one of St. Louis' most fabulous attractions. Refreshments will be served at the conclusion of the tour.
3:30 P.M.	Return to hotel.

WELDING SHOW EXHIBITS AND DEMONSTRATIONS

KIEL AUDITORIUM

Hours of the Exposition

Tuesday, April 15	*12:00 Noon to 10:00 P.M.*
Wednesday, April 16	*10:00 A.M. to 10:00 P.M.*
Thursday, April 17	*10:00 A.M. to 6:00 P.M.*

Admission by registration

HIGHLIGHTS OF EXHIBITS AT 1958 WELDING SHOW

KIEL AUDITORIUM
ST. LOUIS MO.

APRIL 15-18

Acetogen Gas Co. Booth No. 132

Feature: Display of equipment and exhibition of multiple beveling using "Acetogen" gas.

Acorn Iron & Supply Co. Booth No. 700

Feature: Display of bending blocks, welding platens, layout tables, set-up tables, stands, tools and accessories. Also, structural shapes.

Air Reduction Sales Co. Booth No. 401

Feature: Demonstrations of manual Aircomatic® welding equipment, new iron-powder mild-steel and stainless-steel electrodes; electronic-tracer-equipped Duograph for oxyacetylene cutting; custom machine for automatic welding of Bourdon tubes; and brazing.

Alloy Rods Co. Booth No. 204

Feature: Live demonstration of new "Wear-O-Matic" wire-feed unit, a semi-automatic welder for hard-surfacing applications. "Wear-O-Matic" 5-in. diam fabricated wires used during demonstrations. Also, live demonstrations of "Wear-Arc" hard-surfacing electrodes.

All-State Welding Alloys Co., Inc. Booth No. 604

Principal attraction: Demonstration of fluxless "Rubbon" aluminum solder. Full line of aluminum electrodes and flux-coated rods. Jumbo auto-system for "Jet-Flux" brazing. Also, low-fuming bronze and other products.

Aluminum Company of America Booth No. 105

Major issue: Availability and scope of Alcoa's welding, brazing and soldering materials. Typical welded joints will be exhibited and a full-scale inert-gas welding and cutting demonstration will be shown.

American Manganese Steel Division Booth No. 500

Feature: Chrome-nickel-manganese manual rod. Also, complete line of hard-surfacing products: manual rods (arc and torch), including tungsten carbide, automatic and manganese steel weldments.

American Messer Corp. Booth No. 806

Principal attraction: Display of 1 to 10 model of a Messer "Portal" (bridge-type) cutting machine for accurate and precision oxygen cutting of plates.

American Platinum & Silver Division Booth No. 616

Silver brazing techniques will be demonstrated by an on-the-spot brazing job. Also, high-temperature brazing, featuring "Nicrobraz," a Wall Colmonoy product, will be shown. Staff of engineers will be available to answer questions.

American Pullmax Co., Inc. Booth No. 112

Feature: New Pullmax Models P-5 and P-7 universal shearing and forming machine, in operation, demonstrating circle cutting, irregular cutting, beading, joggling, dishing, louvering and slot cutting in sheet metal and plate, including stainless steel.

American Torch Tip Co. Booth No. 130

Feature: Display of new patented multi-use adapters and tips, along with their standard line of cutting and scarfing tips.

Ampco Metal, Inc. Booth No. 404

Feature: Display of layer-wound spooled wire for inert-gas metal-arc process; all-purpose filler rods for gas welding; intricate cold-formed resistance-welding electrodes water cooled to welding face; and other products.

Arcair Co. Booth No. 127

Feature: New Arcair automatic-feed head for machining. Arcair a-c electrodes to utilize an a-c welding machine power source. H-Z light-duty torch with push button, "on-off" air valve, accommodating electrodes to 1/4 in. diam.

Arcos Corp. Booth No. 312

Principal attraction: New developments of stainless and low-alloy rods and electrodes for manual and automatic welding of stainless and low-alloy steels, aluminum and nonferrous metals.

Aro Spot Welder Div. Booth No. 603

Principal attraction: Display of air-operated, suspended spot-welding gun Model 410, which features a new holding device for the welding time, making it a fully automatic gun.

Aronson Machine Co. Booth No. 828

Principal attraction: Geared elevation positioner, and new tank turning rods. Also, display of welding positioners, ram manipulator, turning volts, universal balance positioners, and portable semiautomatic positioner.

Balteau Electric Corp. Booth No. 205

Feature: Display of "Baltospot" 140—140-kv X-ray unit—47 lb—with full ma automatically maintained for all kv settings. Also, "Baltospot" 200—200-kv X-ray unit and other units.

Banner Welder, Inc. Booth No. 206

Principal attraction: Display of a standard projection-type welder on which is mounted special tooling, illustrating method of achieving high production and flexibility of reverting later to standard projection or spot welder.

Berkeley Co. Booth No. 809-N

Principal attraction: Display of newly designed welding unit for producing square or rectangular tubes from formed or rolled channels and angles.

Bernard Welding Equipment Co. Booth No. 209

Feature: Live demonstrations of an entirely new line of "LC" liquid-cooled welding equipment that allows conventional flux-covered electrodes to be deposited at high speeds.

Brennen, Bucci & Weber, Inc. Booth No. 715

Feature: Display of new line of six portable sand-blasting machines. Also, new 200-amp hand portable industrial arc welder.

Cam-Lok Division, Empire Products, Inc. Booth No. 704

Feature: Live demonstrations include

crimping Cam-Lok cable connectors to copper and aluminum cables; cable connections and splices made waterproof and shockproof. Introduction of new 500-amp electrode holder. Display of panel-mounted receptacles, etc.

Cayuga Machine & Fabricating Co., Inc. Booth No. 309

Feature: Cayuga "Tron Drive" demonstrated on new design "Warrior" welding head manipulator, strip welder. Also, display of positioners, turning rolls, seamers, horn jig, ram-type welding-head manipulators, and other equipment.

Champion Rivet Co. Booth No. 110

Principal attraction: Applications of Champion stainless-steel and low-alloy high-tensile electrodes. Test specimens showing weld quality also featured.

Circle Clamp Corp. Booth No. 717

Principal attraction: Do-it-yourself demonstration of "Circle Clamp" products. Featured: a revolutionary new type hose clamp and fastener applied in 3 seconds to hose and cable with ordinary pincers.

Contour Marker Corp. Booth No. 408

Feature: Display of "Contour Marker," Boyce centering head, pipe-flange aligner and 24-in. radius marker.

Coyne Cylinder Co. Booth No. 612

Feature: Display of parts and materials used in construction of Coyne cylinders and lightweight monolithic filler. Latest production methods, including Coyne's submerged-arc welding process, will be explained.

Dockson Corp. Booth No. 725

Feature: New "Dubl-Check" two-stage regulator, an all-forged brass regulator with special metal inlet filter and self-closing pressure relief valve. Will also show its new automatic welding torch in three models.

E. I. du Pont de Nemours & Co. Booth No. 109

Principal attraction: New industrial X-ray film that can be handled in white light, cut in any lengths and eliminates film holders. Length of roll—200 ft.

Emerson Electric Mfg. Co. Booth No. 711

Feature: Display of new Emerson line, featuring a 200-amp d-c gas-engine driven welder.

Erico Products, Inc. Booth No. 140-N

Feature: "Caddy" Type B and H electrode holders, and the new "Caddy" L-163 vulcanizer for "Caddy" splices, lugs and primarily the "Caddy Taper-Lok Quick Connectors." Also, live demonstrations on "Cadweld" connections.

Eutectic Welding Alloys Corp. Booth No. 505

Feature: Continuous demonstrations will show a new technique for inexpensive shop fabrication of high efficiency masonry cutting tools from common shop bolts. Also, "Low Temp Eutec-Rods" for magnesium, stainless steel and copper alloys.

Fibre-Metal Products Co. Booth No. 136

Feature: New products: "Superlectric" electrical safety hats, "Supergrip" electrode holders, "Superlite" aluminum safety hats. Other products: "Superglas," fiberglas safety hats and caps, "Fiberglas" vulcanized fibre welding helmets, "Monarch" face shields and "Weld Prober."

Frommelt Industries Booth No. 602

Feature: Display of new "Porto" welding screen, a pre-fabricated welding curtain with a kit of hardware for assembling a portable framing. Also, "Spa-Fla" safety welding shield, curtains, drapes and blankets.

Glendale Optical Co., Inc. Booth No. 119

Principal attraction: New "soft" welding goggle, moulded of Vinyl and Butirate plastic, designed to fit over all glasses.

Goldsmith Bros. Smelting & Refining Co. Booth No. 703

Feature: Complete line of silver brazing alloys and fluxes for ferrous and nonferrous metals except aluminum and titanium. Also, preformed rings and special shapes of silver-brazing alloys for automatic and semiautomatic operations.

Goss Gas, Inc. Booth No. 800

Feature: Display of welding and cutting tips for all makes of torches, welding and cutting equipment. New products include a line of acetylene-atmosphere air torches.

Harnischfeger Corp. Booth No. 305

Feature: Complete new line of rectifier machines in a-c, d-c and a-c, d-c models, ranges to 680 amp gas-engine driven models. Also, new line of welding positioners with manual or motorized rotation. Complete line of electrodes.

Harris Calorific Co. Booth No. 133

Feature: New combination welding and cutting torch for construction operations and maintenance work; regulators for construction operations; lightweight combination welding and cutting torch. Also, other gas welding, cutting and heating equipment.

Heath Engineering Co. Booth No. 608

Feature: Live demonstration of Heath "Ultra-Graph" oxygen-flame cutting machines introducing new accessories for use in the cutting and welding field.

Hobart Brothers Co. Booth No. 302

Feature: Exhibit of new d-c air-cooled gas-drive welder with a-c auxiliary power; new a-c, d-c welder combination with inert-gas welding facilities; new small-size shop-type a-c transformer. Also, other types of arc welders.

Robert Holmes & Bros., Inc. Booth No. 802

Feature: Display of flux-processing equipment to crush, magnetically separate, and air clean fused flux (as produced by submerged-arc welding); then proportion and blend it with new flux.

Independent Engineering Co., Inc. Booth No. 607

Feature: Scale model of a "liquid" oxygen-nitrogen plant. Equipment designed to produce either liquid or high-pressure oxygen and nitrogen.

Industry & Welding Magazine Booth No. 900-A

Feature: Display of all-new 700-page 1958-59 Welding Directory; information on marketing problems; free copies of "Industry & Welding" and "Welding Illustrated" magazines.

International Nickel Co., Inc. Booth No. 304

Feature: "Incoweld A" wire for dissimilar alloys; "135 Ni-o-nel" electrodes; and "Incohard #1" electrode for low-alloy steels and cast iron subjected to abrasive conditions. Also, other electrodes, wires and fluxes for nickel alloys and cast iron.

Jackson Products, Div. Air Reduction Co., Inc. Booth No. 111

Feature: Neoprene-insulated cable connectors, safety hats (dielectric, fiber glass and aluminum), electrode holders. Also, ground clamps, goggles, welders' helmets, cap-helmet and cap-goggle combinations, eye and face shields.

Kedman Co. Booth No. 614

Principal attraction: Display of "Huntsman" "Years Ahead" fibre glass welding helmet and Model K-1 face shield.

KSM Products, Inc. Booth No. 609

Feature: Exhibit of complete line of full-range stud-welding equipment and studs. Live demonstration with capacitor-discharge stud welders for thin gage ferrous and nonferrous applications; also, other equipment.

Lenco, Inc. Booth No. 509

Feature: Display of Lenco's latest improvements in insulation materials on electrode holders for manual arc welding. Glass fibre tip and handle insulators, nylon spring insulators and bright colors feature HI-AMP products.

Lewis Welding & Engineering Co. Booth No. 115

Feature: Display of standard automatic welding head manipulator and a new control device for automatic welding which will be demonstrated publicly for the first time.

Lincoln Electric Co. Booth Nos. 502 & 503

Principal attraction: New machine for automatic submerged-arc welding, the "Lincolnweld ML-3" a mechanized unit providing automatic wire feed, flux flow and travel speed, but also permitting manual guiding of arc. Also, a-c, d-c "Idealarc" welders.

Liquid Carbonic, Div. of General Dynamics Corp. Booth No. 610

Feature: Bulk-storage customer receivers for liquified oxygen, nitrogen, argon; new "Liquidweld" gas cutting and welding apparatus and supplies; "Dynamic-Arc" welders. Also, cylinder gases, CO_2 gases and apparatus for inert-gas welding.

Linde Company Booth No. 815

Feature: Live demonstration of "Unionarc" welding. Also, display of oxyacetylene welding and cutting apparatus and supplies: "Heliarc," "Sigma," "Unionmelt," "Unionarc" electric welding equipment and air-acetylene appliances.

Marquette Mfg. Co., Inc. Booth No. 506

Feature: "Jet" series oxyacetylene equipment, welder-battery charger combination, powdered-metal-coated hard-surfacing electrodes. Also, full line of arc-welding equipment; oxacetylene welding, cutting and heating equipment; electrodes and gas-welding rods.

McKay Co. Booth No. 405

Feature: Live demonstration of new McKay "Tube-Alloy" semiautomatic hard-surfacing welding wires. Also, exhibit of stainless-steel and hard-surfacing welding electrodes. Introduction of several new grades of McKay low-hydrogen electrodes.

Merit Co. Booth No. 600

Feature: New portable spot welders; timing electronically controlled; water-cooled tips; arms and transforming air operation optional.

Metallizing Company of America Booth No. 827

Feature: Automatic push-button eyeled production metallizing. "Borocote" metallizer: sprayed chromium boride for protecting metals against attack of molten aluminum. "Rokide" metallizing: Norton Co.'s aluminum oxide, zirconium oxide and zirconium silicate rods. "Mogul" metallizing equipment.

Metallizing Engineering Co., Inc. Booth No. 107

Principal attraction: Display of three new pieces of metallizing equipment, including electronic metallizing machine and automatic control panel. Also, operating exhibit spraying either powdered ceramics or hard-surfacing alloys.

Metal & Thermit Corp. Booth No. 409

Feature: Demonstration of new high-speed "Speedex Triplex" iron-powder electrodes, and introduction of new line of automatic hard-surfacing wire called "Hardex-Auto." Also, complete line of electrodes, accessories and machines.

Miller Electric Mfg. Co., Inc. Booth No. 507

Feature: "Gold Star" d-c, a-c and a-c, d-c welders; inert-gas metal-arc welders with controlled slope; gasoline-engine driven welder and welder-power plant; M180P utility welder. Also, spot welders, "Gold Star" SRH horizontal-type d-c welder.

Milwaukee Electric Tool Corp. Booth No. 719

Feature: Display of $\frac{1}{2}$-in. electric hammer and $\frac{1}{4}$-in. angle head for pistol drill. Also, sander-grinders, aerial grinders, drills, hammers, polishers and saws.

Modern Engineering Co. Booth No. 606

Feature: New pressure-molded multi-seat block for welding, cutting, therapy and industrial regulators. Also, full line of oxyacetylene welding and cutting apparatus and brazing equipment.

Moehlenpah Engineering, Inc. Booth No. 615

Principal attraction: Display of resistance-welding equipment, automatic arc-welding equipment, fixture and plier clamps, pneumatic valves and electrodes.

National Cylinder Gas Co. Booth No. 210

Feature: Display and demonstration of their "RS" cutting machine. "Dual shield" and "Argonarc" semiautomatic arc welding. The NCG "Beetle," "Rego" and "Torchweld" hand welding and cutting apparatus. Tube Turns welding fittings.

National Torch Tip Co. Booth No. 713

Feature: New cutting and welding torches, new air-acetylene brazing units, new natural-gas cutting and welding tips, and complete replacement parts for all gas cutting and welding equipment.

Nelson Stud Welding Division, Gregory Industries, Inc. Booth No. 510

Feature: Display of "NS-10" stud-welding gun, weighing less than 4 lb and designed for welding of studs through $\frac{1}{2}$ in. diam.

Nuclear Systems Division of Budd Co. Booth No. 822

Feature: Display of five radiography machines. These will range from light-weight "Model 40 Iriditron" for field use to the "Multitron 1060" which is capable of containing up to 1000 curies of Cobalt 60.

Page Steel and Wire Division Booth No. 808

Principal attraction: Two new welding analyses especially designed to eliminate porosity resulting from CO_2 gas-shielded welding: "A-8-30" is "A-8-20-G" with 0.75 aluminum added; A-8-15 MO "special" has 0.60 silicon added.

Pandjiris Weldment Co. Booth No. 307

Feature: "Model 12 x 12 RBM" welding head manipulator with operator's pulpit and power rotation, an internal longitudinal seamer for 18 ft lengths, 3000-lb positioner with "Pan Grip" work holding clamp; and 100,000-lb turning rolls.

Philips Electronics, Inc. Booth No. 407

Principal attraction: "Norelco" equipment spotlights industrial radiography by featuring a range of X-ray equipment from 30 kvp to 300 kvp, capable of radiographing welds up to 3 in. thick.

Picker X-Ray Corp. Booth No. 714

Principal attraction: Display of new 750-curie Cobalt 60 machine for the radiography of 2 to 10 in. of steel. Also, new 100-curie Iridium machine and latest portable X-ray equipment.

Pure Carbonic Co. Booth No. 400

Principal attraction: Display of new high-pressure "CO_2 Receiver" assembly; new 8100 Series CO_2 regulators—flowmeters—automatic CO_2 electric heater and other miscellaneous carbon dioxide "Carboflex" equipment.

J. M. Ragle Industries, Inc. Booth No. 710

Feature: Round aluminum soapstone holder. Also: tip cleaning drill kits, torch lighters and flints, white metal welding rod, goggle bands, welders' caps, chipping hammers, hose ferrule crimpers, hose and cable measuring machine.

Reid Avery Co., Inc. Booth No. 706

Feature: Display of automatic welding heads with corrugated wire feeders; new iron-powder low-hydrogen electrodes. Also, mild-steel, stainless-steel, low-hydrogen and special-alloy electrodes, etc.

Robotron Corp. Booth No. 412

Principal attraction: Resistance-welding controls built to specifications of major users will be featured to exemplify how controls can be tailored to specific plant requirements.

Robvon Backing Ring Co. Booth No. 139

Feature: Display of Robvon backing rings for weld pipe joints. Available in carbon steel, wrought iron, chrome-moly alloys, stainless steel and aluminum. Machined backing rings to any standard or custom specification.

Joseph E. Rush Co. Booth No. 724

Feature: Thomson Electric Welder "Synchro-shear" color movies. Electroloy's specialized electrodes and holders for resistance welding. Also, full line of resistance-welding machinery and electrode materials.

Safety Clothing and Equipment Co. Booth No. 701

Feature: Complete line of welders' protective clothing, consisting of gloves, sleeves, aprons, coats, leggings, curtains and goggles. Highlight: new tungsten-arc welding jackets and lightweight chrome leather clothing.

Sciaky Bros., Inc. Booth No. 313

Feature: Initial display of "SR O" rocker arm spot welder. Its compact control is transistorized and uses printed circuits; also, has plug-in feature.

Sellstrom Manufacturing Co. Booth No. 501

Feature: Display of new "Jumbo" welding and chipping goggle and welding "Magnifier" helmet plate. Also, entire line of "Sellstrom Safeguards" eye and face protective equipment.

Sight Feed Generator Co. Booth No. 135

Feature: Display of "Rexare" twin head "MS-8" multiple spindle roller and idler welder and positioner. Mounts eight tractor rollers. Lays pass on both sides of roller simultaneously.

A. O. Smith Corp. Booth No. 125

Feature: Display of complete line of welding machines ranging from farm welders to 1500-amp constant-potential power supplies plus welding electrodes and accessories.

Smith Welding Equipment Corp. Booth No. 403

Feature: Full line of oxyacetylene cutting, heating and welding equipment. Principal attraction: new line of high-speed precision cutting tips. Also, exhibit of air-acetylene, air-propane equipment for soldering, heating and light brazing.

Square D Co. Booth No. 605

Principal attraction: Combination electronic resistance-welder controls of completely new design featuring individual plug-in panels including tube or relay-type valve control and tube or relay-type ignitron firing.

Steffan Engineering Booth No. 129

Feature: Vari-bevelling attachment for "Mechanical Draftsman," new equipment for cutting of stainless-steel pipe, elbow sectioning attachment for "Mechanical Draftsman." Also, pipe-contouring machine, mechanical hole cutter.

Stoody Co. Booth No. 617

Feature: Operating display of automatic electric welding head; semiautomatic welding machines operating both open-arc manually and submerged arc with small positioner. Exhibition of various hard-surfaced parts from St. Louis area.

Sylvania Electric Products Inc. Booth No. 118

Feature: Exhibit of complete line of tungsten electrodes for shielded-arc welding, including 2% thoriated, 1% thoriated, "Puretung" and "Zirtung." Display will emphasize that partially used rods need not be scrapped for lack of identification.

Taylor-Winfield Corp. Booth No. 100

Feature: Exhibit of miniature resistance welders, special high-production welders; counting tube and new design combination welding controls; tangent benders and other metal-forming equipment. Also, complete lines of electric resistance and arc welders.

Tec Torch Co., Inc. Booth No. 506-N

Principal attraction: Live demonstration of Tec torches and Tec spot guns for tungsten-arc welding; also, "Visuweld" equipment such as transparent nozzle for "Cinemascope" welding and spot welding "around corners."

Tempil° Corp. Booth No. 207

Feature: Demonstration of "Tempilstiks°" by trained personnel, with special emphasis on techniques for determining temperatures in connection with welding operations. "Tempilstiks°" for 2050 and 2100° F will be available for first time.

Tweco Products, Inc. Booth No. 611

Feature: Newly designed line of "Tweecotong" electrode holders, ground clamps and "Tweco" splicers using the ball-point type cable connection. "Tweco" cable connectors with Neoprene covers. "Tweeco-Lite" aluminum welding cable.

Uniflex Cable Division Booth No. 707

Feature: Electro-plating cables and danglers, heavy-duty secondary cables for electric furnaces, cables for induction heating. Also, complete line of secondary cables, jumpers, shunts and connectors for resistance welding.

Unique Equipment, Inc. Booth No. 303

Feature: Display of powered turning rolls and positioner line, featured by stationary backup plate and a new bench model positioner, 200-lb capacity hollow-spindle unit for inert-gas welding. Also, other equipment.

United Wire & Supply Corp. Booth No. 114

Feature: "Sil Flux Black Label" for use at elevated and prolonged temperatures, aluminum welding and brazing alloys. Also, complete line of low-temperature silver-brazing alloys and silver-brazing fluxes.

Vacuum Tube Products Co., Inc. Booth No. 824

Feature: Spot- and seam-welding equipment for welding of light-gage materials, including resistance and capacitance discharge types with new hydraulic and portable heads.

Valvair Corp. Booth No. 137

Feature: Display of newly developed integral mounted welding valve. This valve cap mounts on welding cylinder and meets J.I.C. requirements.

Vickers, Inc. Booth No. 121

Feature: 500-amp constant-potential welder; 400-amp combination standard-constant potential welder. Also, standard 200-, 300- and 400-amp magnetic amplifier-rectifier d-c arc welders; welding accessories, including start and tail stop controllers and others.

Victor Equipment Co. Booth No. 508

Feature: Display and demonstration of complete line of hard-surfacing alloy rods and automatic hard-surfacing wire; Victor flame-cutting and welding apparatus; and new high-pressure gas regulators with remote control features.

Wall Colmonoy Corp. Booth No. 411

Principal attraction: Colmonoy "Sprayweld" unit and Colmonoy "Sprayweld" process. Also, display of various welding rods and brazing alloys as well as fabricated assemblies from Walleo Manufacturing Division.

Webb Corp. Booth No. 809S

Feature: Display of their newest designs in mast and boom fixtures, welding positioners, turning rolls and longitudinal seam welders.

Welding Alloys Mfg. Co. Booth No. 509A

Feature: Display of "Walco" aluminum welding and brazing alloys, bronze cable, lenses and cover glass, electrode holders, atmospheric air-acetylene and propane torches, rubber hose and equipment.

Welding Engineer Publications, Inc. Booth No. 113

Principal attraction: Revised edition of "Welding Engineer" data sheets and "The Welding Distributor." Also: "Welding Engineer," monthly magazine; The Welding Encyclopedia, Jefferson's Gas Welding Manual and The Oxyacetylene Welder's Handbook.

Martin Wells, Inc. Booth No. 720

Feature: "Tong-Grip" electrode holders in complete range up to and including 500 amp; available in either copper or Wells-Litealloy. Also, "Rod Saver" and "Suregrip" electrode holders.

Welsh Manufacturing Co. Booth No. 721

Principal attraction: Head and eye protection equipment. Highlight: new softside welding and chipping goggles.

Weltronic Co. Booth No. 208

Feature: "Weltronare" rectifier type d-c arc welder available with silicon diode or selenium rectifiers. Complete line of d-c welders provide units for all applications, including fully automatic sequence. Operation on both inert-gas processes.

Westinghouse Electric Corp. Booth No. 103

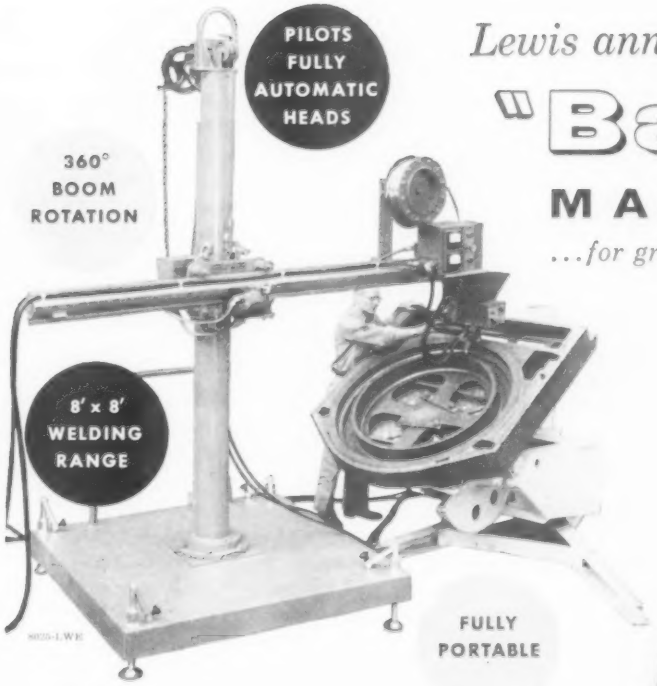
Feature: New portable hand gun for gas-shielded welding of aluminum, mild and stainless steels, bronze, copper and magnesium. Will also show automatic control for resistance welding; X-ray nondestructive testing and other equipment.

Wheelabrator Corp. Booth No. 504

Feature: Operating exhibit of a 48-in. wheelabrator saving table demonstrating the airless blast method of cleaning weldments and structural steel members.

Worthington Corp., Positioning Equip. Div. Booth No. 300

Feature: 240 welding positioner—24,000 pounds capacity—with Servo speed electronic drive, power elevation, and post mounted. Model "O" one-ton power and idler roll. 12 x 12 welding manipulator and other equipment.



Lewis announces the versatile new

"Bantam"

MANIPULATOR

...for greater savings in automatic welding

Fabricators get new versatility for automatic welding operations... at remarkably low cost... with the LEWIS "Bantam" manipulator. Designed to handle diversified fabrications, short production runs and special jobs, this machine features infinitely variable welding speed... extreme accuracy with boom-tip loads up to 250 pounds... manual or powered elevation.

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BOOTH 115

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For more details, circle No. 107 on Reader Information Card

Dr. Comfort Avery Adams

1868 - 1958

Dr. Comfort Avery Adams died at his home in Philadelphia on Friday, February 21st. He was 89 years old.

Often referred to as the dean of American engineers, Dr. Adams was the founder of the American Welding Society and also served as its first national president.

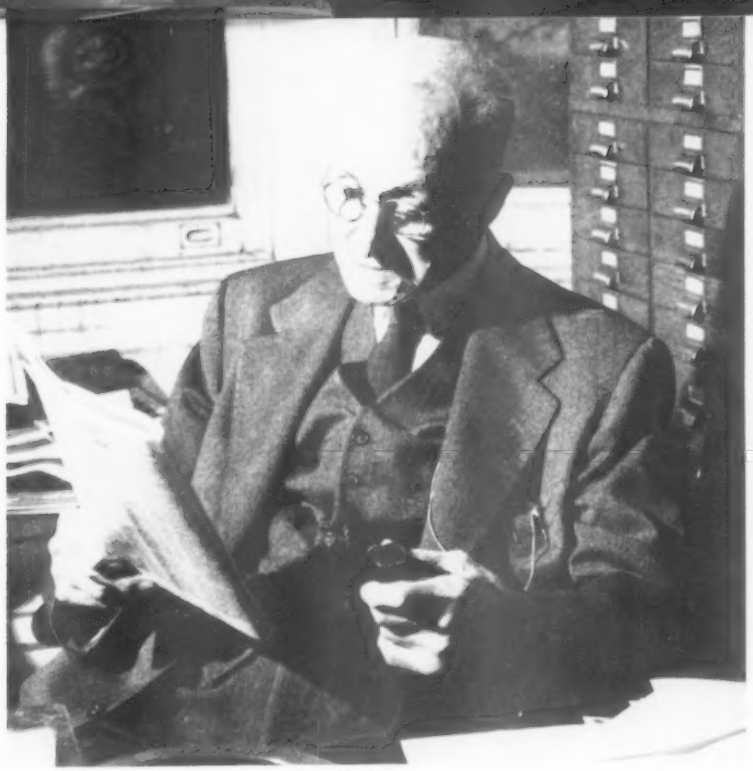
A native of Cleveland, he received a B.S. degree in mechanical engineering from Case School of Applied Science in 1890. During his undergraduate years, Dr. Adams served as laboratory assistant to Dr. Albert A. Michelson, the inventor of the interferometer.

In 1890 he was one of a group of young men who traveled to latitude 55°, Alaska, to study and report on Glacier Bay and its glaciers. This team brought forth a report on measurements made on the site of the movement of glacier ice. Their findings resulted in the correction of a previously estimated movement of 70 ft per day to a recorded movement of 7 ft per day. From 1890 to 1891, Dr. Adams had two jobs. For the first six months he was assistant to the chief engineer of the Brown Hoisting and Conveying Machine Co. of Cleveland, and assisted in the design of two cantilever cranes for the Newport News Shipbuilding Co., which were in successful operation for many years thereafter. During the last half of this year, he was engineer for the Brush Electric Co., also of Cleveland, where he designed two large d-c generators for the Rochester Electric Light Co. and participated in the design of the first gearless traction motor.

He began his career as an educator in 1891 when he was appointed an instructor in electrical engineering at Harvard University's Lawrence Science School. He was promoted to an assistant professorship in 1896 and to a full professorship in 1906. In 1914 he was named Abbott and James Lawrence Professor of Engineering. Although he was dean of the Harvard Engineering School in 1919, his extracurricular activities as president of the AIEE and the American Welding Society, and as chairman of the Engineering Division of the National Research Council, together with his consulting work, prompted him to resign as dean in order to avoid sacrificing his teaching work. The additional title of Gordon McKay Professor of Electrical Engineering was granted Dr. Adams in 1936, the year of his retirement from the Harvard faculty.

The birth of the American Welding Society goes back to World War I when Dr. Adams, through an appointment from President Woodrow Wilson, served as chairman of the Welding Committee of the Emergency Fleet Corp., an organization dedicated to the application of welding to the building of ships. It was a result of this association that prompted Dr. Adams to spearhead the founding of the Society in 1919. The Board of Directors of the Society later elected him an honorary life director. In 1935 he organized the Welding Research Council and served as its first chairman. He was later given the post of honorary chairman of this group. Dr. Adams delivered the first Adams Lecture in 1943.

Included in this list of citations presented to Dr. Adams were the Miller Medal, honorary membership in the Harvard Engineering Society, membership in the



National Academy of Sciences, an acknowledgment of gratitude from the Council of National Defense, the honorary degree of Doctor of Engineering from Case School of Applied Science and a citation from the president of the United States. President Eisenhower said in part: "Dr. Adams has achieved an outstanding record of public service and has won the abiding esteem and affection of his fellows in the engineering profession. His career is an inspiration and a challenge."

A fellow of the American Academy of Arts and Sciences, Dr. Adams also held membership in the Franklin Institute Committee of Sciences and Arts.

In 1900 and succeeding years through 1956, Dr. Adams presented papers on alternator regulation, synchronous, induction, centrifugal and repulsion motors, high-frequency induction furnaces and many other branches of electrical engineering. He not only pioneered in the design of electrical machinery but also in high-voltage electric cable. The American Institute of Electrical Engineers presented him in 1940 with the Lamme medal "for his contributions to the theory and design of a-c machinery and his work in the field of electric welding." In 1956 he was awarded the Edison Medal by AIEE "for pioneering achievements for the development of alternating current electric machinery and in electric welding; for vision and initiative in the formation of an engineering standards organization; and for eminence as an educator and consulting engineer."

He also helped to found the American Standards Association and served as its first chairman.

Dr. Adams' consulting work covers forty-five years for the Okonite Co., fifteen years for the General Electric Co., thirty years for the Babcock and Wilcox Co., fifteen years for the Budd Co., ten years for the Warner Sugar Refining Co., two years for American Sugar Refining Co., eleven years for the American Tool and Machine Co. and numerous other associations for shorter durations. His achievements through consultation work included the invention of the thrust-wheel-type cableway towers used in the construction of numerous dams, the invention of automatic spillway gate systems used on many of the country's largest dams, the development of modern highway construction, causes of gas explosions and sugar purification.

Dr. Adams was instrumental in the establishment of code rules relating to the welding of pressure vessels and boilers through his association with the Boiler Code Committee of the American Society of Mechanical Engineers.

During the week of April 8, 1957, the AMERICAN WELDING SOCIETY honored its founder and first president by giving the official title of the Adams National Meeting to its 38th annual spring meeting in Philadelphia. The Adams National Dinner, also honoring Dr. Adams, was held on Monday evening of that week at the Sheraton Hotel, at which time a portrait of Dr. Adams was presented to the scientist. Over 600 members and guests of the SOCIETY attended this memorable affair.

Dr. Adams is survived by a son, John, of Concord, Mass., and a grandson, Ian Adams.

THINGS YOU SHOULD KNOW

(That Happened in February)

● The 1957 Annual Meeting and Welding Exposition, held in Philadelphia last April, were dedicated to Dr. Comfort Avery Adams, Founder, First President and Honorary Director of the AMERICAN WELDING SOCIETY. The death of Dr. Adams is noted elsewhere in this issue. Former Secretary Joe Magrath, who conceived and so effectively developed the plans for the meeting dedicated to Dr. Adams, has written "a gentleman and a kindly and gracious teacher has left us, but his spirit cannot perish. His passing marks the ending of an era and of his footsteps. His boots may well be destroyed for there is none who can wear them."

● A meeting of your Board of Director was scheduled to be held in New York on February 24th. The opening time for the meeting was advanced to 7:00 A.M. so that necessary business could be completed and the meeting adjourned at 11:00 A.M., permitting officers and Members of the Board to attend the funeral of Dr. Adams, which was held in Philadelphia that afternoon. President Sander, Past President Clyle, Second Vice-President MacGuffie, Director Chouinard, WRC Director Spraragen and Staff Members Mooney and Plummer were among those able to go to Philadelphia.

● On Feb. 11, 1958, Ernest Victor David was stricken with a fatal heart attack. For many years he was very active in SOCIETY affairs and during the period 1935 to 1949 served as Chairman of the National Program Committee or Convention Committee. He retired in 1954 from his activities with Air Reduction Sales Co. and became owner and manager of apartment houses in Santa Monica, Calif.

● With Chairman C. E. Jackson and Staff Member Art Phillips, the Educational Activities Committee held a meeting in Columbus, Ohio on February 5th. A number of new committees were organized in connection with the development or revision of manuals and educational material. The Air Reduction Co. is presenting to the SOCIETY the copyrights covering its manuals on welding and cutting and on the design of welded steel structures. Representatives of NEMA have discussed the possible distribution by the SOCIETY of chapters on welding processes and welded joints suitable for inclusion in engineering design courses. A manual on the welding of aluminum alloys may be published. A new AWS Manual of Arc Welding is available and will be reviewed by a committee with F. C. Saacke as chairman. At the Saint Louis meeting in April Educational representatives from each Section will be invited to meet with District Directors and other SOCIETY officers and EAC members in an open discussion session.

● On February 5th your Secretary met with Chairman Biers and Secretary Spraragen of the American Council of the International Institute of Welding to discuss problems involved in securing effective representatives of industry in the United States to act as members of the Commissions of the Institute. At the Board of Directors meeting on February 24th it was agreed that your Secretary should also assume the duties of Secretary of the American Council of the IIW at the beginning of 1959.

● On February 6th Past-President Humberstone and Chairman MacGuffie of the Reserve Funds Committee met with staff members, and by telephone with Treasurer Rockefeller, to review the various reserve and contingent funds now held by the SOCIETY and to prepare recommendations covering objectives, goals, contributions to the funds and use of income earned by the funds. These recommendations were presented to a joint meeting of the Finance and Executive Committees on February 23rd and then approved with minor revisions by your Board of Directors on February 24th.

● Bela Ronay on February 11th visited headquarters and discussed the possibility of establishing an AWS Institute for teaching welding technology—an activity of the type now being developed by ASM.

● On February 13th President-Elect Hoglund and First Vice-President-Elect MacGuffie met at headquarters to discuss reserve funds, preliminary 1958-59 budget problems and the SOCIETY publicity and public relations programs. As Chairman of the Welding Information Program, Mr. MacGuffie prepared a report recommending that solicitation of funds for an Information Center be discontinued and that provisions be made in the 1958-59 budget for staff members who would devote their time to these activities. These recommendations were later approved by members of the Manufacturers, Finance and Executive Committees and finally by the Board of Directors.

● During the weekend of February 15th and 16th cold weather, snow and wind completely disrupted transportation along the eastern coast and far inland, stopping airplanes, trains and even busses. Your Secretary tried valiantly and vainly all day February 16th and 17th to reach Pascagoula and Birmingham and never did get beyond Atlanta, Ga. He promises to try again at an early date.

He did reach Miami on February 18th to join Past Director Tom Berg, Program Chairman Perry Kennerk, Chairman H. J. Hoodwin and a large group of South Florida Section members at an enthusiastic evening meeting. Your Secretary described SOCIETY activites and presented a technical discussion of welded-plate construction. He was delighted to be greeted by Past-President A. C. Weigel (1944-45) who had driven more than 200 miles from his home in Bradenton, Fla. in order to attend the meeting. "Al," who retired from his activities with Combustion-Superheater Corp. some time ago, is in good health, enjoying life in Florida and wants to send greetings to all his friends in AWS. (Note: A winter overcoat felt quite comfortable.)

● Carolina Section Officers O. K. Barnes, Jr. and T. M. Jenkins met your Secretary at the Raleigh airport the following afternoon and drove him to North Carolina State College for a conference with Dean of Engineering Harold J. Lampe and Professors Anderson and Cope, the latter also being Chairman of the Carolina Section. Later your Secretary was speaker at a dinner meeting of the Section and participated in an unusually long and lively question period. Several members including Secretary H. B. White and J. F. Martin expressed interest in problems connected with qualification, certification and registration of welders.

● February 21st was made memorable by a visit at Clemson College in South Carolina where examples of student "snow sculpture" remained as evidence of an unprecedented 6-inch snowfall the preceding Saturday. Here Professor J. H. Couch and three associates under Department of Industrial Engineering Head E. J. Freeman give orientation courses in welding to more than 400 engineering and agriculture freshmen each year. Advanced courses are offered to Juniors and Seniors in these same fields. Your Secretary gave an inspirational-type talk to a large assembly of students. Professor Couch has written a book on Manufacturing Processes and Procedures with excellent sections on Welding and Allied Processes. Contacts such as these definitely show that welding is being recognized as the preferred method of joining metals and that engineering and other students are being taught fundamentals of welding processes and welding design.

● A combined meeting of the Organization Structure and the Constitution and

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(continued on next page)

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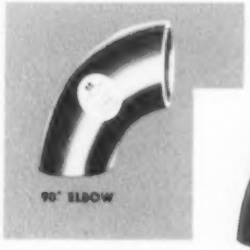

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Bylaws Committees was held at SOCIETY Headquarters on the morning of February 24th with Chairmen Chounard and Oehler in charge. During the afternoon a joint Finance-Executive Committee meeting was held with President Sander presiding. Both of these meetings were held to consider and finalize recommendations which were presented to the Board of Directors at their meeting the following day.

● At the Board meeting which was scheduled early, as noted, recommendations of President-Elect Hoglund for 1958-59 National Nominating Committee were approved. C. P. Sander will act as Chairman with L. C. Bibber, J. E. Dato and T. B. Jefferson as Members-at-Large and the eleven District Representatives completing the committee. This committee will hold an open meeting during the Annual Meeting at Saint Louis. Members may attend and offer suggestions of names for national offices.

● The Board of Directors also decided to: (1) issue Handbook Section for calendar year to new B members; (2) discontinue the issuance of a directory because of cost and limited use; (3) approve recommendations concerning reserve funds, publicity, and HW Secretary as previously mentioned.

● President Sander returned to New York following the funeral of Dr. Adams in order to spend February 26th at headquarters completing actions initiated at the Board of Directors meeting and handling other matters referred to the SOCIETY and requiring his attention.

Fred L. Plummer

Resolution

Ernest Victor David

On Tuesday morning, Feb. 11, 1958, Ernest Victor David was stricken with a fatal heart attack in his home in Santa Monica, Calif. He was 65 years old.

For 5 years, commencing in 1935, he served the SOCIETY as secretary of the National Program Committee. The National Programs of the SOCIETY, up to 1935, were on a modest scale. Mr. David, in that year, became chairman of the Program Committee. He was convinced that the National Programs of the SOCIETY should be made an accessible forum for all its members and for industry to present the latest and best information available—successful procedures, new products, processes, apparatus, research and test results and educational papers. With his unique organizational and administrative ability he secured the enlistment of leading corporations in establishing this program. By this means, using the vast distribution organizations of industry it was possible to develop many excellent papers and, through the medium of simultaneous sessions, arrange for their presentation. This innovation resulted in an unusual growth in Annual Meeting attendance.

In 1940 Victor became chairman of the Convention Committee. His genial personality, his methodical and systematic methods resulted in wholehearted cooperation of the host Sections and by the ASM. He relinquished the post of chairman in 1949.

Mr. David studied mechanical engineering at the University of Pennsylvania and in Switzerland. During World War I he was chief engineer of the USS *Pennsylvania*. In the postwar years he served in capacity of boiler inspector for a large insurance company; was affiliated with the design, production and operation of an early industrial oil burner; and was associated with the engineering department of a large central steam heating utility company in the East.

In 1929, Mr. David joined the Air Reduction Sales Co. in the Applied Engineering Department. He rose to the position of assistant manager of this department. At the time of his retirement in 1954, Mr. David was engaged in the selection and training of technical personnel.

In addition to Victor's long and significant contributions to AWS he found time to contribute to other engineering and technical societies. He was a member of the American Society of Mechanical Engineers. For a time he served in various official capacities in the Metropolitan New York Section. Among these activities was that of chairman of the Iron and Steel Division which covered welding applications. The International Acetylene Association also benefited from his contributions. Here he served on the Oxyacetylene Committee and was national treasurer of IAA for a number of years.

Victor was not idle after his retirement. Within a year he became the owner and manager of two apartment houses in Santa Monica.

He is survived by his wife Margaret and two sisters.

RESOLVED, That this appreciation of Ernest Victor David, a man of kindly forthright character, a great organizer and a man respected and loved by all, be entered in the records of the AMERICAN WELDING SOCIETY and be it further resolved that a copy of this appreciation be sent to Mrs. Margaret David as our expression of our common loss and our share in her sorrow.

●

Two New Supporting Companies

Two more companies have been enrolled as Supporting Company members of the AMERICAN WELDING SOCIETY. They are Nashville Bridge Co., Ft. Shelby St., Nashville, Tenn., and Ocean Accident & Guarantee Corp., Ltd., 1 Park Ave., New York 16, N. Y.

Both enrollments are effective March 1, 1958.

INSTRUCTIONS

FOR

PROSPECTIVE AUTHORS

Authors who plan to submit papers for publication in THE WELDING JOURNAL are invited to send for a free copy of the booklet "Instructions and Suggestions for Authors."

All requests should be addressed to Editor, THE WELDING JOURNAL, American Welding Society, 33 W. 39th St., New York 18, N. Y.

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EDUCATIONAL ACTIVITIES

The Technical Institute in Welding Education

by Roy McCauley

The need for technicians in industry is becoming more and more apparent. In many industries, graduate engineers are engaged to do the work of technicians and are kept in this category for an excessive period of time.

Despite the talk of recession and unemployment, this period of reconstruction will pass and the need for engineers and related personnel will be greater than ever. The situation can be evaluated only from a national point of view and with a statistical approach.

Henry H. Ormsby, Engineering Education chief, estimates that 75,000 engineers will graduate in 1960. In analyzing the technician situation he stated, "Various studies indicate that industry needs from two to five technicians for each engineer." If the present level of interest in technical institute work is maintained, it is estimated that 16,000 technicians would be graduated in 1960.

In the year 1960, therefore, we could expect 75,000 engineers to become available and only 16,000 technicians to work with them. The proportion of one engineer to five technicians is reversed. There would be one technician to work with five engineers.

The president of Link Aviation Co. emphasized the need when he said, "We have approximately 120 graduate engineers at Link. We also have about 120 trained technicians—not nearly enough. We probably should have a ratio of at least three technicians to every engineer."

Technical Institute Material

The technical institute is primarily the training ground for the man of action. It is no place for the dreamer or the man who covets a steam-heated environment and prefers the clatter of a typewriter to the hum of machinery.

Somewhere along the line a misconception has arisen. The technical institute is no "second best" program for individuals who cannot make the grade in college. It is for a different type of person altogether—different in outlook, different in temperament and different in skill.

The institute is designed to teach the student who has a "feeling" for tools, who is impatient to come to grips with practical applications and who would view with the utmost distaste the fundamental training essential for the graduate engineer.

This man, the future technician, will play a prominent part in the new world of automation we are entering.

	Type of schools				
Year	State and municipal	Privately owned	Extensions of college and university	Total welding technology graduates	Total graduates of industrial curriculum in technical institutes
1953	49	1	1	51	6,207
1954	37	2		39	6,971
1955	46	10	45	101	11,350

The Technical Program

Despite the obvious need for technicians there are insufficient enrollments for the supply to meet the demand by 1960. If 75,000 engineers are to be graduated in 1960, we will need an estimated 375,000 technicians to service these engineers. All we can expect are 16,000.

An investigation into the cause of this serious deficiency reveals two causes: lack of technical institutes and ignorance of the program. In numbers we cannot even begin to compete with Russia's 800 technicums. This is a problem for the future. If we can arouse the interest, we can obtain the institutes.

Ignorance of the program is more serious. It would appear that the very people who recommend educational processes following high school graduation are entirely ignorant of the aims and possibilities of the technical institute.

The Remedy

First and foremost, this requires an educational approach to show how all levels of technical ability are urgently required. It must be realized that desirable as an engineering degree may be, the long years of study are beyond the endurance capacity of many people. Career counselors are wrong when they advise students that engineering is the only career in industrial technology and that they had better enter other fields if they cannot take the complete engineering program.

Countless technicians are lost to industry by this unimaginative counseling. Furthermore, many students who are unable to complete their engineering course drift off into other industries. A large percentage of these students would be invaluable as technicians if they could be steered into technical institutes to complete their training. Many would welcome the opportunity if they knew it existed.

Our need is for welding technicians and our objective is to make known to the student the opportunities in this field. At the same time we must provide literature for the counselor in order that he too will be aware of the opportunities in welding—he must also be told where the training for these opportunities may be obtained.

The need for a program of this type is very clear when a comparison is made between the number of students graduating and the number graduating in welding technology from technical institutes.

Percentagewise, there has been little change in welding technology graduates since 1953.

It is very obvious that insufficient courses in welding are given and too little interest has been aroused among students. The mere handful of 101 welding technicians graduated, compared to 11,350 industrial technicians, is very revealing.

The implications are very serious. The welding engineer, who has been hampered for lack of competent technical assistance, can look for no relief in the near future. It takes two years to train a welding technician, and before we can start training there must be courses available and students to enroll.

It is only by revealing the facts that appropriate action can be taken. EAC has uncovered the facts, but it will take the combined effort of all to provide the remedy. •

Professor Roy McCauley, Chairman of the Department of Welding Engineering, Ohio State University.

Aluminum Welding Featured at Midwest Conference

Three new processes for welding aluminum were revealed at the 4th Annual Midwest Welding Conference held in Chicago on January 29th and 30th.

The methods were described by F. R. Baysinger, head of the welding branch of the metallurgical research department of Kaiser Aluminum and Chemical Corp., which developed the processes.

Their development followed two years of research into the causes of porosity in aluminum welds which found hydrogen to be the major offender.

In summarizing the processes, Mr. Baysinger said one process uses a trace of chlorine with argon down the contact tube and normal shielding flow in the outer cup to provide high quality welds in a flat position; the second, low flows of argon in the contact tube plus nitrogen in the outer shield to provide a low cost means of welding pure aluminum, or aluminum bus, and the third, a low flow of argon with a low flow of argon or helium in the outer shield for all position, all alloy code-quality welding at lower cost.

The Baysinger paper was one of 12 technical discussions presented at the conference which was sponsored by Armour Research Foundation of Illinois Institute of Technology and the Chicago Section of the AMERICAN WELDING SOCIETY.

Approximately 225 welding engineers attended the two-day meeting on the Illinois Tech campus.

Two papers on brazing applications were read by Frank J. Filippi, project liaison engineer of Solar Aircraft Co., who described the fabrication of brazed honeycomb panels used in aircraft and missile construction, and A. M. Setapen, manager of the engineering division of Handy and Harman, who discussed novel production brazing applications.

Other papers covered reports on T-1 steel by Perry C. Arnold, welding engineer, Chicago Bridge and Iron Co.; welding of chromium-molybdenum alloy steel piping, by J. Bland, head of the metals and welding section of the engineering research department, Standard Oil Co. (Indiana); brittle fracture by P. P. Puzak, head of the welding section, Naval Research Laboratory; and design for welding by Omer W. Blodgett, design consultant, Lincoln Electric Co.

Others covered developments in power sources for welding by Warren Sykes, chief electrical engineer, Miller Electric Manufacturing Co.; automatic resistance-welding applications by Thomas C. Falter, welding engineer, Frigidaire Division of General Motors Corp.; manual electrodes for code governed weldments by Amel R. Meyer, chief of welding research, Graver Tank and Manufacturing Co.; new CO_2 welding process by A. F. Chouinard, manager of the research and development department, National Cylinder Gas Co., and nickel-alloy welding of dissimilar alloys by metal-arc and inert-gas processes by K. M. Spicer, assistant supervisor, mechanical engineering section, International Nickel Co.

MIDWEST WELDING CONFERENCE REVEALS NEW PROCESSES

Delegates to the 4th Annual Midwest Welding Conference are shown at the opening session in Chicago on January 29th

Photographed at the second day of the conference are (*left to right*) J. W. Kehoe, K. M. Spicer, Harry Schwartzbart and Thomas L. Dempsey

Three of the speakers at the January 30th session in Chicago were (*left to right*) Warren Sykes, A. F. Chouinard and Amel R. Meyer

Section News and Events

as reported to Catherine O'Leary

UNIVERSAL FIXTURING

Fort Wayne, Ind.—The *Anthony Wayne* Section met on January 23rd for dinner and a meeting at the Hobby Ranch House. Speaker was Willard Gunzelman of the World Electric Co., Cleveland, Ohio. His topic was "How the Putting on Tool Grew Up!" Mr. Gunzelman covered the topic of universal fixturing for small job shops to use the latest automatic welding equipment. Slides were shown which were followed by open discussion.

PANEL DISCUSSION

Birmingham, Ala.—The regular monthly meeting of the *Birmingham* Section was held on February 18th at Gulas Restaurant.

Scheduled speaker was Fred L. Plummer, national secretary, but, due to the very bad weather conditions prevailing at the time, he was unable to get to Birmingham. Needless to say, this was a disappointment to the members of the Birmingham Section, but the program chairman promised to make arrangements for Mr. Plummer to be their guest during the next season at a more suitable time. The Section awards Mr. Plummer an A for trying.

A panel discussion was arranged and proved to be lively and interesting. Those partaking in the panel were Messrs. J. R. McFarland, A. E. Pearson, R. E. Clotfelter and E. H. Turnock.

The program ended with the showing of a new U. S. Steel research film.

IRON-POWDER ELECTRODES

Boston, Mass.—Over ninety members and guests met in the Westinghouse Auditorium in South Boston on February 10th for the monthly meeting of the *Boston* Section.

With the social hour and a roast beef dinner under their belts, a most receptive audience gathered to hear Lt. A. L. Lonsdale narrate the U. S. Coast Guard's exploration of a new West to East "Northwest Passage" from Point Barrow to Davis Straits. He prefaced his remarks by stressing the geographical closeness of the two most powerful nations in the world at this point and then continued to give a running commentary to a color film which recorded all of the drama and excitement of the voyage by three small Coast Guard cutters. This presentation set the stage for the technical session that followed.

Jerry Hinkel [illegible], of the Lincoln Electric Co. spoke on "Mild-Steel Iron-Powder Electrodes." This somewhat controversial subject was

SECTION MEETING CALENDAR

MAY 3

LEHIGH VALLEY Section. Ladies' Night.

NORTH CENTRAL OHIO Section. Ladies' Night.

MAY 8

SAGINAW VALLEY Section. Saginaw, Mich. "Aircraft Welding," P. Gordon Parks, Solar Aircraft Co.

ST. LOUIS Section. Ruggeri's Restaurant, St. Louis, Mo. "Welding Advances in Ship Fabrication," W. R. Guest, Jr., Ingalls Shipbuilding Co.

MAY 9

CLEVELAND Section. 19th Annual Symposium.

TOLEDO Section. Seventh Annual Dinner Dance. Toledo Edison Club, Toledo, Ohio.

MAY 11

NORTHWEST Section. Elks Club, Minneapolis, Minn. Dinner 6:30 P.M. Annual business meeting.

MAY 13

DAYTON Section. Annual Quiz Program.

MAY 15

IOWA Section. Annual business meeting with entertainment and refreshments.

MICHIANA Section. South Bend, Ind.

MAY 16

NEW YORK Section. Annual Dinner Meeting. Toots Shor Restaurant, New York, N. Y.

MAY 17

DETROIT Section. Annual Ladies' Night Party. 6:00 P.M. Latin Quarter.

STARK CENTRAL Section. Second Annual Ladies' Night. Mergus Restaurant, Canton, Ohio.

MAY 20

NEW HAMPSHIRE Section. Manchester, N. H. Queen City Motel. Dinner 7:30 P.M. "New Economies in Maintenance Welding," John Duffy, Eutectic Welding Alloys Corp.

OLEAN AND BRADFORD Section. Dinner at Fossett House in Wellsville, N. Y. Plant visit to the Air Preheater Corp. in Wellsville.

MAY 21

PROVIDENCE Section. Dinner meeting at Johnston's Hummocks, Providence, R. I. 6:15 P.M. "Why Different Electrode Types," D. B. Howard, ACF Industries, Inc.

MAY 22

DETROIT Section. Engineering Society of Detroit. 8:00 P.M. "Magnetic Force Welding of Vinyl Coated Steel," A. W. Schueler, Precision Welder and Flexopress Corp.

NIAGARA FRONTIER Section. Continental Inn, Kenmore, N. Y. Dinner 6:45 P.M. Meeting 8:15 P.M. "Welding Aluminum and Its Alloys," F. R. Baysinger.

ST. LOUIS Section. Coronado Hotel, St. Louis, Mo. Annual Banquet.

MAY 23

INDIANA Section. Technical session and dinner. 6:30 P.M. "Welded Steel Fabrication," Perry Arnold, Chicago Bridge & Iron Co.

NORTHWESTERN PENNSYLVANIA Section. Erie, Pa. Annual business meeting and ladies' night.

HARTFORD Section. Lighthouse Inn, New London, Conn. Annual dinner dance and election of officers for 1958–59 season.

MAY 24

MILWAUKEE Section. May Party.

PHILADELPHIA Section. Annual dinner dance.

Editor's Note: Notices for July 1958 meetings must reach Journal office prior to May 1, so that they may be published in June Calendar. Give full information concerning time, place, topic and speaker for each meeting.

GUNZELMAN SPEAKS ON UNIVERSAL FIXTURING

Willard Gunzelman was the guest speaker at the January meeting of the Anthony Wayne Section. He discussed the universal fixturing for small job shops to use the latest automatic welding equipment

presented in an unbiased way that gave due credit to the proper application of these electrodes plus the "old stand bys" E-6010, E-6012, E-6020 and the more recent low-hydrogen groups. His theme of "fast fill, fast follow and fast freeze" was an attention-arresting presentation and all in attendance agreed that this was one of the better meetings this year.

PLATE FABRICATION

Raleigh, N. C.—The regular monthly meeting of the *Carolina* Section was held in the Colonial Room of the S&W Cafeteria in Raleigh on February 20th.

Guest speaker was Fred L. Plummer, national secretary. Mr. Plummer gave a talk on "Design For Welded Plate Fabrication" which was accompanied by color slides dealing with design, fabrication, materials, joint preparation, welding procedures and sequence, distortion control, inspection and testing of large metal storage tanks fabricated from mild steel, stainless steel and aluminum alloys. There was also a lengthy discussion on qualification of welders for pressure vessels and structural work.

DISSIMILAR METALS

Cleveland, Ohio.—K. M. Spicer [illegible], with the Development and Research Division of the International Nickel Co., was the technical speaker for the February 12th regular meeting of the *Cleveland* Section. His subject was "The Joining of Dissimilar Metals by Metal-Arc and Inert-Gas Processes." His illustrated talk was highly interesting and informative. In spite of bad weather, a large group attended the dinner and technical session. Mr. Spicer's experience with nickel, high-nickel alloys and nickel-containing alloys in relation to all joining processes well qualifies him to present information on the subject.

ANNUAL SOCIAL

Cleveland, Ohio.—The *Cleveland* Section held its annual social event on Friday evening, February 21st. The annual "ladies' night" was a successful get-together for members, guests, friends and their ladies. The affair, arranged by Eva Karnatz and her committee, consisted of dancing, French-style entertainment (including the can-can), food and refreshment, and an impressive group of door prizes. Refreshments in the early part of the evening were "on-the-house," supplied by a sponsoring group of companies.

STUD WELDING

Denver, Colo.—The *Colorado* Section held its regular dinner meeting on February 11th at the El Rio Grande Cafe in Denver. Dinner was preceded by a social hour during which a tremendous amount of "welding" was accomplished.

Featured speaker was Ray Lucas, Denver branch manager of the Nelson Stud Welding Division of Gregory Industries, Inc. He touched on some high points in the history and development of the stud-welding process. He explained the "how" and "why" of the process and equipment. A live demonstration was made and members were invited to weld studs themselves. Mr. Lucas is to be complimented on an excellent presentation.

PLANT TOUR

Dayton, Ohio.—On Tuesday, February 11th, sixty-five members and guests of the *Dayton* Section toured the Inland Manufacturing Division of General Motors Corp. at Dayton, Ohio.

During the course of this very interesting tour, those present saw re-

CINCINNATI SECTION ADDRESSED BY SCHUSTER

Large group attended the January 28th meeting of Cincinnati Section to hear William Schuster speak on the production welding of modern freight cars

LADIES' NIGHT HELD BY CLEVELAND SECTION

General dancing was enjoyed by those present at the Ladies' Night event sponsored by the Cleveland Section on February 21st

"French-type" entertainment was provided by "Can-Can" girls—the highlight of the floor show

Ross Yarrow, Mrs. Flocke, Frank Flocke, Mrs. Mayor and William Mayor (left to right) enjoying the "refreshments"

DETROIT SECTION SPEAKERS

Dinner speaker at the February 14th meeting of Detroit Section was Wallace Perkins who demonstrated the art of "fishing for fun"

E. B. Lutes was the technical speaker for the evening. His subject dealt with arc-welding electrodes

HARTFORD SPEAKER

Robert L. Peaslee spoke on design and brazing of jet components for high-temperature service at the February 18th meeting of Hartford Section

sistance-welding operations carried out in production of automotive steering wheels, ball joints and motor mounts. Also included were tours of the plastic, rubber and ice cube/tray departments.

A welcome coffee break was provided by the host at the midpoint of the tour allowing guests time to compare notes and rest their tired feet.

ARC-WELDING ELECTRODES

Detroit, Mich.—The regular meeting of the *Detroit* Section held on February 14th at the Engineering Society of Detroit in the Rackham Building was well attended considering the bad weather. To those who like to fish, the dinner speaker, Wallace Perkins of Parms Sporting Foods, Royal Oak, gave an excellent talk on rod and reels.

The regular meeting held at 8:00 P.M. in the Auditorium was well-attended also. The speaker, E. B. Lutes (MS), vice-president of Arcrods Corp., gave an interesting talk on arc-welding electrodes which was well-received.

RESISTANCE WELDING

Detroit, Mich.—The *Detroit* Section held a special technical meeting on Thursday, February 20th at the Engineering Society of Detroit. This was a very good meeting and of special interest to resistance-welding operators and others. Four excellent films were shown and Messrs. R. V. Anderson and G. F. Ellsworth of National Electric Welding Machine Co. conducted a very interesting discussion on

different phases of resistance welding. The film on numerical positioning illustrated the control of 1500 successive predetermined spot welds and could be very useful if needed for production. General resistance-welding applications, push-rod welding and brake-shoe welding were the other films shown and discussed.

JET-ENGINE COMPONENTS

Glastonbury, Conn.—On Tuesday night, February 18th, thirty hardy souls of the *Hartford* Section braved extremely cold temperatures and twelve inches of snow to hear an excellent talk by Robert L. Peaslee [M], vice-president of Wall Colmonoy Corp., Detroit, Mich. Invited guests from aircraft industries in and around the Hartford area, as well as section members, were impressed by Mr. Peaslee's knowledge of his subject, "Design and Brazing of Jet Engine Components." He spoke of heat control, atmospheric control and cleanliness as important factors in high-temperature brazing.

MAINTENANCE WELDING

Allentown, Pa.—Cares C. Keyser, Bethlehem Steel Co., Steelton plant, was the speaker at the February 3rd dinner meeting of the *Lehigh Valley* Section held at Walps Restaurant in Allentown. Mr. Keyser's subject, "Maintenance Welding," was illustrated with slides of a variety of items repaired or rebuilt by various applications of welding.

The speaker showed applications of automatic and semiautomatic submerged-arc welding in maintenance work. On some machine parts it was necessary to design and build special jigs and setups to handle the work.

Examples of maintenance work by hard surfacing wearing parts and then machining these surfaces were discussed by the speaker. Mr. Keyser closed his talk by explaining how to weld continuous crane runway rails with stainless-steel electrodes.

A question-and-answer period on technical details of maintenance welding followed.

In his second appearance before the Section as coffee speaker, T. D. Shanahan, Sales Department, Bethlehem Steel Co., continued his interesting talk, illustrated with slides, on antique automobiles.

WELDING ALUMINUM ALLOYS

Houston, Tex.—The *Houston* Section held its monthly meeting on February 26th at the Ben Milam Hotel. Featured speaker was 1st Vice-President G. O. Hoglund, manager, Welding Section, Process Development Laboratory, Aluminum Company of America. His subject was "Arc Welding the Aluminum Alloys."

Before Mr. Hoglund was introduced, District No. 9 Vice-President P. V. Pennybacker addressed the audience of 135 members and guests, stating that the leadership of the SOCIETY was backed by the individual members who should give their full support to those in office.

HOUSTON SECTION HEARS HOGLUND ON ALUMINUM WELDING

Gus O. Hoglund, AWS first vice-president, speaking on arc welding of aluminum alloys

Some of the members and guests who were present at the February 26th meeting of the Houston Section

District No. 9 Vice-President P. V. Pennybacker shown addressing those present

Section past chairmen on hand were, seated (*left to right*): A. E. Wisler, W. H. Greer, T. J. Kegg and E. C. Jackson. Standing (*left to right*): P. D. Morgan, James Earthman, H. H. Wehner, L. F. Megow and L. H. Courtright

OLSEN GIVES TALK ON TITANIUM WELDS

Microcracking in titanium welds was the topic of Robert P. Olsen's talk before the Aircraft & Rocketry Panel on February 6th

Discussing the subject on hand at the Los Angeles meeting are (*left to right*) Earl Lund, Charles Smith and E. O. Williams

All of the past chairmen of the Section were honored on this occasion. Those present were: L. H. Courtright, 1938–39; E. C. Jackson, 1944–45; T. J. Kegg, 1946–47; A. E. Wisler, 1948–49; L. F. Megow, 1950–51; W. G. Greer, 1953–54; James Earthman, 1954–55; H. H. Wehner, 1955–56; and P. D. Morgan, 1956–57. Counting the present chairman Roy Pringle, this made ten of twenty chairmen heading the Houston Section since it started in 1937. A fine tribute was paid to Ben Allen, deceased, who was chairman for 1952–53.

As soon as Mr. Hoglund started his talk, the listeners discovered that they were being addressed by a top-notch expert in the broad aluminum field whose knowledge was equally as broad.

The three major developments in aluminum have been (1) the manufacture of stronger aluminum alloys, (2) the improvement in performance of aluminum welds and (3) the new welding processes.

Several of the desirable characteristics of aluminum were pointed out such as its excellent resistance to corrosion, its being nonmagnetic, and, of course, the weight advantage.

Many uses of aluminum were described, and slides gave illustrations of truck tanks, one large storage tank 125 ft in diam, diesel-engine bases, piping and structural members.

It was interesting to note that aluminum bus bars with aluminum filler-metal joints were in greater use than all other types of metal bars combined.

Fatigue tests of aluminum proved that resistance to fatigue was not increased by changing the alloying elements. Also, it was noted that no embrittlement of this metal occurs when low temperatures exist.

An excellent film was shown which described the best aluminum welding and cutting processes.

MICROCRACKING IN WELDS

Huntington Park, Calif.—The February 6th meeting of the *Aircraft and Rocketry Panel, Los Angeles* Section, featured a paper presented by Robert Olsen, senior research engineer of North American Aviation Co., Inc., Los Angeles, Calif. The title of Mr. Olsen's paper was "Microcracking in $\frac{1}{8}$- to $\frac{3}{16}$-in. Titanium Welds."

Other than serving as an officer in "Uncle Sam's" Navy, Mr. Olsen has been active as a research and welding engineer since leaving Stanford University. Previous to his becoming a member of the North American engineering staff, Mr. Olsen was welding engineer of several power-plant and refinery construction projects for the Bechtel Corp. Mr. Olsen's paper covered the complete metallurgical and chemical investigation conducted to determine the cause of microcracks found in fusion welds during the fabrication of certain large titanium parts for the Navaho missile.

Mr. Olsen's investigation disclosed that the cracks were caused by microembrittlement and rigidity of parts; however, chemical analysis, microhardness and microstructure surveys found these parts to be within acceptable limits.

Unique types of tests were shown to verify this theoretical conclusion and to evaluate various welding procedures to make certain that crack-free welds could be made prior to future produc-

STAINLESS-STEEL WELDING COVERED BY THOMAS

David Thomas presenting his paper on "Problem-Solving in Stainless-Steel Welding" before Los Angeles Section members on February 20th

Section Chairman Dave O'Connor congratulates James Kay, winner of the scholarship award for this year

Russ Graves and President "Sandy" Sander talk over old times prior to meeting

tion. Mr. Olsen's talk was well supported by slides and appreciated by all those in attendance.

The dinner meeting was held at the Elks Lodge in Huntington Park.

STAINLESS-STEEL WELDING

Huntington Park, Calif.—One hundred seven members and guests of the *Los Angeles* Section convened at the Elks Club, Huntington Park, Calif., on February 20th, to enjoy cocktails, dinner and a program of exceptional merit presented by R. David Thomas, Jr. M'43, president of the Arcos Corp., Philadelphia, Pa.

Mr. Thomas has been with the Arcos Corp. since graduating from Cornell University. His master's thesis on "Reductions in Arc Welding" began his career in the arc-welding field. Mr. Thomas' subject for the evening was "Problem-Solving in Stainless-Steel Welding." Methods and procedures needed in the fabrication and control of chemistry in materials used were emphasized upon cracking which is prevalent in the welding of stainless steel without the needed control. Mr. Thomas' paper was well supported with slides.

Before presenting his paper, a movie in color was shown on the use and development of the EB insert by the Electric Boat Co.

INERT-GAS WELDING

Madison, Wis.—Seventy-five members and guests of the *Madison* Section met at the Eagles Club on February 15th to hear a very interesting talk on "Modern Application of Inert-Gas-Shielded Tungsten-Arc Welding," as given by Harry A. Huff M'42, of the Air Reduction Sales Co., New York. The coffee speaker was Captain Harry E. Scarborough of the 327th Fighter Group, Truax Field, Wis., who presented an excellent talk on F-102 Fighter Jets.

NONDESTRUCTIVE TESTING

Baltimore, Md.—On the evening of February 21st the regular meeting of the *Maryland* Section was held jointly with the local chapter of the Society for Non-Destructive Testing at the Baltimore Engineers Club.

Arthur L. Pace, Eastern Zone sales manager for the General Electric Co., Newark, N. J., presented a very informative talk on destructive-testing applications to the welding industry. Mr. Pace pointed out the economic factors as well as the various test result factors that should be considered in choosing a particular type or size of testing equipment. Radiographic, magnetic and sonic testing equipment all have their particular applications on fabricated equipment. Slides were shown listing the uses of the test methods and economic factors as well as actual equipment in use.

A lively question-and-answer period followed, indicating the interest aroused by the very excellent talk.

STRUCTURAL WELDING

Manchester, N. H.—The *New Hampshire* Section met on February 18th for a joint meeting with the New Hampshire Chapter, AIA, and the New Hampshire Society of Engineers, Inc. at the Queen City Motel in Manchester. The meeting was also attended by many members of the New Hampshire Public Works Department, Bridge Division.

GAS-SHIELDED WELDING DISCUSSED BY HUFF

Harry A. Huff was the principal speaker at the February 13th meeting of the Madison Section. His topic covered tungsten-arc welding applications

Tom McElrath, Ed Shevey and Walter Stark were the lucky winners of the door prizes. That accounts for the smiling faces

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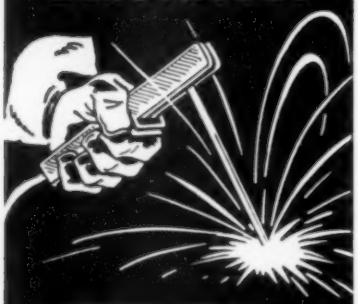

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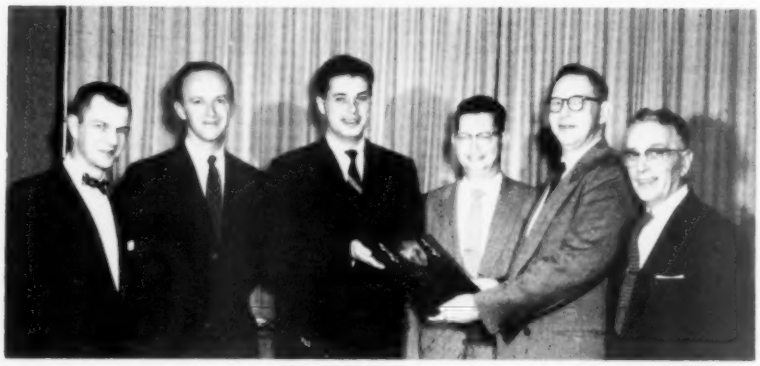

Cincinnati Section team won quiz program sponsored by North Central Ohio Section on Dec. 6, 1957. Shown (*left to right*) are team members, R. McDonald, R. Losee, Captain Stan Weiss, George Hoppin III, Section Vice-Chairman R. L. McKinney and A. Paolina, member of Section Executive Committee

LaMotte Grover [illegible], welding engineer, Air Reduction Co., New York, was the featured speaker. Mr. Grover's topic, "Structural Welding," was very well-received as indicated by the lengthy question period which followed his lecture. This was Mr. Grover's first official visit to New Hampshire but it is hoped not the last.

Other distinguished guests were: John Betley, president of the New Hampshire Chapter AIA; Leroy F. Johnson, president of the New Hampshire Society of Engineers, Inc., and Harold Langley, bridge engineer, New Hampshire Department of Public Works.

PRESSURE-VESSEL FABRICATION

Newark, N. J.—W. R. Apblett, Jr., chief metallurgist for the Foster-Wheeler Corp., was the speaker to a very interested audience at the January 21st dinner meeting of the *New Jersey* Section held in the Essex House Hotel in Newark. Mr. Apblett's subject was "Pressure-Vessel Fabrication for Nuclear Service."

With the aid of slides and motion pictures, Mr. Apblett described in detail the construction of parts of a nuclear vessel made from 7-in. thick stainless-steel slabs formed into two half radii at a 300°F preheat. Each half was made in two steps under an eight thousand ton press; these were later cut, U-groove machined and welded by the submerged-arc process. The heat treatment and quench of these sections were accomplished in the open at the Mountain Top plant.

Mr. Apblett's other topics were the stainless-steel cladding of heavy steel heads showing the equipment and methods used, also automatic inert-gas tungsten-arc welding of tubes to tube sheets in heat exchangers.

The interest stimulated by his talk was evident by the long question-and-answer period that followed.

A dinner preceded the technical meeting, followed by a film in color entitled "Bright Steel" (courtesy Bethlehem Steel Co.), showing the processing of tin plate from ore to the finished product.

The evening's activity was concluded by a social get-together with refreshments.

JOB SHOP WELDING

New York, N. Y.—The second meeting of the new year of the *New York* Section was held on Feb. 11, 1958. The speaker of the evening was Irving S. Feiner, welding engineer for P. Feiner and Sons, Inc., New York 36, N. Y.

Mr. Feiner had selected "Job Shop Welding" as his topic, a subject with which he is well acquainted.

The speaker lectured about the unique characteristics of job shop welding, varying from, for example, the repair of a small casting or a gear, to the fabrication of a structure running into thousands of dollars. He explained that because of this a job shop welder has to be a layout man and a mechanic, and has to be able to think for himself and, in many cases, develop and devise the means of satisfactorily completing a particular job.

Mr. Feiner also discussed the economics of job shop welding and the methods that have to be used in arriving at selling prices for the many types of work performed. Basically, such selling prices are based upon the cost of materials, cost per inch of

welding, plus cost of overhead and profit.

Mr. Feiner willingly agreed that the back bone of the job shop welding business is the welder.

Prior to the technical meeting, Bela Ronay, retired head of the Welding Laboratory, U. S. Naval Engineering Experimental Station, Annapolis, Md., gave a short and very interesting extemporaneous talk about the relationship of welding to rockets and missiles and the present missile race in which the United States has entered.

Those present at this meeting, approximately 60 engineers and welders, enjoyed the meeting, as evidenced by the number of questions that were asked.

John Mikulak of the Worthington Corp. was the technical chairman.

As usual, the meeting was held at Victor's Restaurant, 1 E. 35th St., New York City, where an excellent dinner was served prior to the meeting.

WELDING T-1 STEEL

Buffalo, N. Y.—Forty-eight members of the *Niagara Frontier* Section visited the Bethlehem Steel plant on the afternoon of January 23rd. After the tour, dinner was served at the Continental Inn prior to the regular monthly meeting at which 70 members were present.

The technical speaker for the meeting was Leon C. Bibber AWS, chief research engineer of welding for the U. S. Steel Corp. His subject was "Welding of Quenched-and-Tempered Steel (T-1 Steel)."

Mr. Bibber went into detail in describing the weldability of T-1 steel and the testing that was conducted to show the advantages of using "T-1 Steel" for pressure-vessel construction. His presentation was understood by all, both technical and non-technical members.

The speaker's excellent talk was supplemented with the showing of slides and colored motion pictures illustrating the physical characteristics of "quenched-and-tempered steel," and the burst tests of pressure vessels. A question period followed in which Mr. Bibber answered all questions to the fullest extent.

METAL SPRAYING

Oak Ridge, Tenn.—The *Northeast Tennessee* Section, in a joint meeting with the Oak Ridge Chapter of the Society for Non-Destructive Testing, had the pleasure of having Walter B. Meyer AWS, as guest speaker for the February technical dinner meeting held at the Oak Terrace in Oak Ridge on Feb. 18, 1958.

Mr. Meyer, president of the St. Louis Metallizing Co., is currently serving as president of the Metco System Contractors, an organization consisting of a number of metal-spraying firms, of which his company is a member.

Mr. Meyer's presentation included a description of the metallizing process, the equipment involved and a brief resume of its history. He discussed the engineering specifications surrounding the application of sprayed metal coatings, including the manner of surface preparation, the types of abrasives used and the necessary equipment, the types of metals which can be used, thickness of application and also the types of sealers that can be applied over the sprayed metal coating. The talk was well illustrated by color slides.

Prior to the meeting, thirty members and guests of the AWS and SNT chapters enjoyed a social period followed by a delicious hot buffet supper.

RESISTANCE WELDING

Menands, N. Y.—W. C. Rudd, vice-president in charge of engineering for the New Rochelle Tool Corp., New Rochelle, N. Y., was the speaker at the February 6th dinner meeting of the *Northern New York* Section held at Panetta's Restaurant in Menands. His topic was "High-Frequency Resistance-Welding Techniques, Advantages and Applications."

After dinner, fifteen minutes were devoted to a "welding clinic." Topic for the evening was cast iron welding.

DISTORTION CONTROL

Erie, Pa.—J. R. Stitt AWS, research and welding engineer for R. C. Mahon Co., Detroit, a recognized expert on distortion in this country, spoke on "Distortion and Its Control" at the January 21st meeting of the *Northwestern Pa.* Section held at Larson's Restaurant in Erie.

PRESSURE-VESSEL CONSTRUCTION

Erie, Pa.—Leon C. Bibber AWS, chief research engineer—welding, in the Applied Research Laboratory of the U. S. Steel Corp., was the speaker at the February 18th meeting of the *Northwestern Pa.* Section held in Larson's Restaurant in Erie. Mr. Bibber spoke on "The Suitability of Quenched-and-Tempered Steels for Pressure-Vessel Construction." Mr. Bibber is presently the authority on the weldability of various steels manufactured by U. S. Steel and consulting engineer in connection with the application of those products.

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STAINLESS-STEEL FABRICATION DISCUSSED BY LINNERT

Part of the overflow crowd that attended the February 13th meeting of the St. Louis Section

George E. Linnert was the principal speaker. His topic—stainless-steel fabrication

RADIOISOTOPE TESTING

Bradford, Pa.—Despite very bad driving conditions due to stormy weather, seven members from Olean drove 12 miles to hear J. A. Rains of the Picker X-Ray Corp., give a most interesting talk on radioisotope testing at the February 18th meeting of the *Olean-Bradford* Section.

MILD-STEEL ELECTRODES

Philadelphia, Pa.—The big snowstorm in the middle of February disrupted many normal pursuits, but failed to stop the regular monthly meeting of the *Philadelphia* Section on February 17th. The speaker was Orville T. Barnett [illegible], assistant manager of Metals Research at Armour Research Foundation in Chicago.

Mr. Barnett presented a series of slides which rated the 60-series electrodes. The electrodes were evaluated for heavy butts and fillets, light sheet metal, restraint, speed, penetration, appearance and undercutting, soundness, ductility, low-temperature impact strength, freedom from spatter, ability to bridge gaps, easy slag removal and results on coated steel. He then summarized by showing a series of slides using these evaluations to determine the most suitable electrodes for specific applications. The talk was followed by a long and interesting discussion.

Mr. Barnett should be commended for his efforts in keeping the engagement in the face of the worst storm in many years. Those hardy souls who attended were well-repaid for their effort.

PANEL DISCUSSION

Pittsburgh, Pa.—One hundred five members and guests of the *Pittsburgh* Section took part in a panel discussion on "What Welding Process Should I Use?" Panel members and their subjects were as follows: W. B. Brubaker, Air Reduction Sales Co., "Gas Welding and Cutting;" M. L. Powers, Linde Co., "Inert-Gas Welding;" J. M. Cooper, Taylor Winfield Corp., "Resistance Welding"; C. W. Lytton, Lincoln Electric Co., "Manual and Submerged-Arc Welding."

A short talk by each panel member on the basic principles of each process was made. Following these formal presentations an extensive question-and-answer and open forum discussion followed.

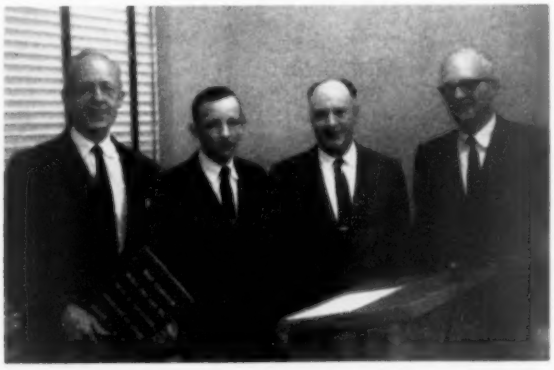
The meeting was held in the Mellon Institute of Industrial Research. The dinner with an attendance of 63 was held at the Hotel Webster Hall in Oakland.

STAINLESS-STEEL FABRICATION

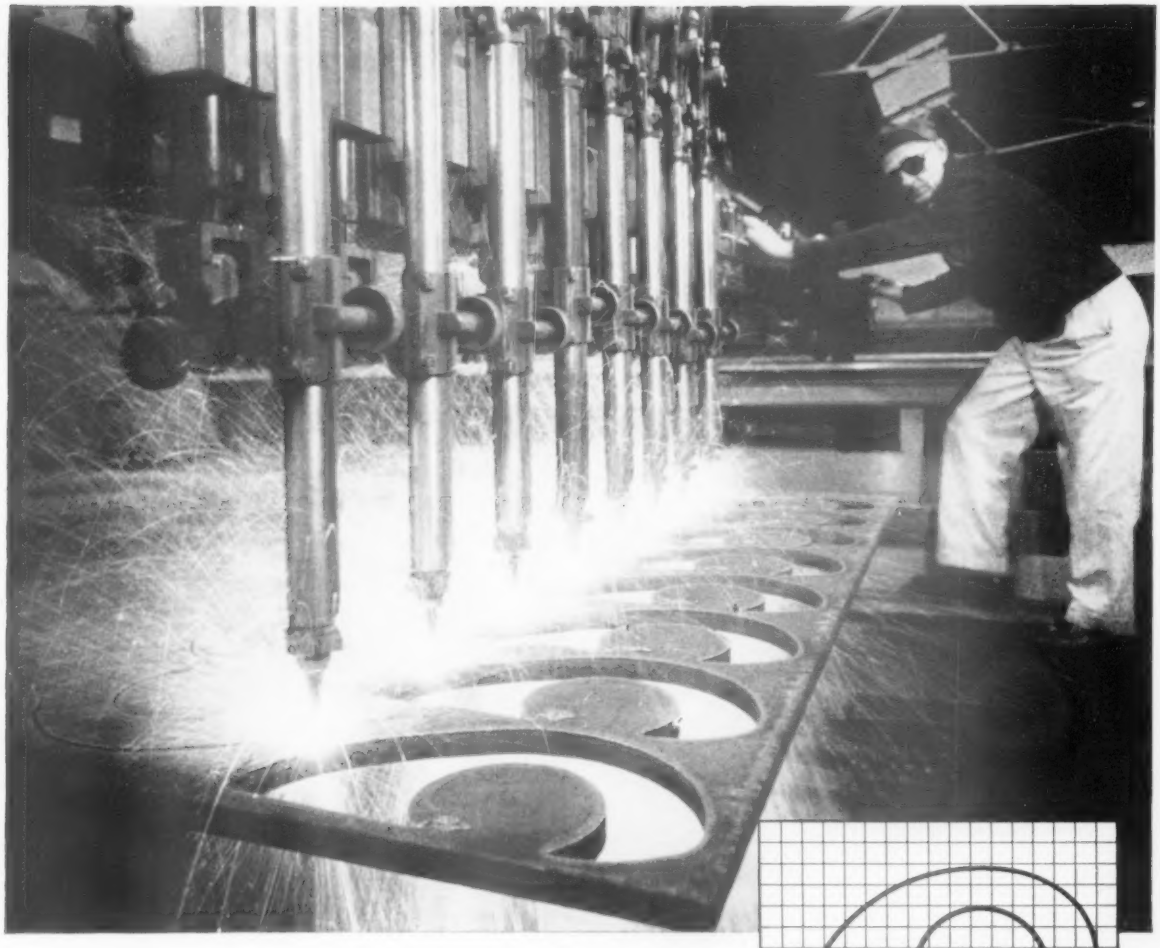
St. Louis, Mo.—The largest turnout of the season, 120 members and guests, was present at the February 13th meeting of the *St. Louis* Section held

PANEL DISCUSSES WELDING OF DISSIMILAR METALS

Enthusiastic audience was in attendance at the Panel discussion sponsored by the Philadelphia Section on February 7th



Panelists who dealt with welding of dissimilar metals were (*left to right*): H. C. Campbell; L. K. Poole, moderator; F. E. Garriott and K. M. Spicer



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SAN FRANCISCO BAY AREA PLAYS HOST TO NATIONAL OFFICERS

President Sander poses with officers of Santa Clara Valley Section at January 21st meeting in South Palo Alto. Seated (*left to right*) are J. Grafton, treasurer; President Sander and M. J. Sebastian, chairman. Standing (*left to right*) are R. N. Skow, 2nd vice-chairman; F. Nelson, secretary; V. S. Zacharenko; and A. M. Hubbard, 1st vice-chairman

Discussing a point at the January 20th meeting of the San Francisco Section are (*left to right*) W. F. Ajello, past chairman; Fred Stettner, past chairman; President Sander; C. W. Doggett, chairman; C. B. Robinson, director of District #11; Secretary Plummer; and Lee Tinnes, technical representative

Several members of California Polytechnic College's Student Chapter assemble with Chairman C. W. Doggett of the San Francisco Section prior to meeting Secretary Plummer on January 23rd. Shown (*left to right*) are John Morgian, Bill Walker, Chairman Doggett, Jim Miller and Professor R. C. Wiley

At a gathering of members of the Central Valley Division of the San Francisco Section during the January 22nd meeting in Sacramento are, seated (*left to right*) C. W. Doggett; President Sander; P. Jonas, chairman; and F. H. Stevenson. Standing are (*left to right*) H. A. Reynolds, Steve Welz, Jr., D. R. Moore, M. A. Sweeney and R. E. Labaugh, secretary treasurer

in Ruggeri's restaurant. One hundred and thirty-four turned out for the meeting which followed.

Featured speaker at the meeting was George E. Linnert, of the Armco Steel Corp., who presented an excellent talk on stainless-steel fabrication. This talk was of great interest to the many tank fabricators in the area. This interest was evidenced by the number of questions put to Mr. Linnert during the question session after his talk.

The coming annual meeting to be held in St. Louis was discussed and the "Queen City" is preparing to show their guests hospitality fit for a king.

STAINLESS-STEEL WELDING

San Jose, Calif.—R. David Thomas, Jr., president of Arcos Corp., Philadelphia, Pa., was the guest speaker at the February meeting of the *Santa Clara Valley* Section held in the Hawaiian Gardens, San Jose on February 25th. The subject of Mr. Thomas' talk was "Problem-Solving in Stainless-Steel Welding."

Mr. Thomas divided his talk into two sections, both of which were very well-received. Mr. Thomas has the ability to explain data in an easy, yet thorough way.

He explained the first part of his talk, a theoretical treatise on Type 347 welding rod and its metallurgical problems, in chart form. Mr. Thomas explained the difficulties in welding steel piping for high-temperature steam power plants, cracking in base metal for temperatures above 1000° F. Several graphs illustrated ductility at elevated temperatures of stainless steel.

The second half of his talk covered economic aspects for stainless-steel use by weld overlay on mild steel. Submerged-arc welding for overlay was stressed as being most economical. Slides also illustrated one- and two-layer overlay.

STORAGE TANKS AND PRESSURE VESSELS

Miami, Fla.—National Secretary Fred L. Plummer was the guest speaker at the regular monthly meeting of the *South Florida* Section held on February 18th at the Miami Firemen's Benevolent Association Hall. Among the members and guests present was Al Weigel, a past president of the Society.

Before taking up the assigned business topic, Mr. Plummer gave a résumé of the expansion of the Society

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Completely automatic welding . . . guided by hand with the "Mechanized Squirt Welder"

Here's how you can get the speed and sureness of automatic welding . . . plus portability and versatility never before heard of in submerged arc welding.

Mechanized gun is propelled at any preset speed while electrode and flux are fed from an all day supply on the compact, portable control unit.

- Accurately controlled speeds from 1 to 70 inches per minute.
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- Guides in any direction without fixtures.
- Deep penetration of submerged arc welding.
- Easy to make beautiful welds.
- High operator appeal—light gun, no helmet.

TRIGGER—*Single trigger starts and stops flux flow, wire feed, and welding current.*

SPEED CONTROL AND REVERSING SWITCH—*Speed control dial calibrated in inches per minute. Can be changed while welding. Reversing switch determines direction of travel.*

TRAVEL MOTOR AND DRIVE WHEEL—*Propels gun in any direction at desired speed.*

ELECTRODE—*(3/32" or 5/64")—Feeds continuously from 60 lb. coil in control unit through extra flexible cable.*

MOTOR MOUNT—*Travel motor can be adjusted up or down to control flux coverage and rotated around the gun to change travel direction. Control wire coupling disconnects for quick removal of entire travel mechanism for manual operation.*

FLUX—*Granular flux feeds through tube from tank on control unit to small reservoir on gun. Flows from gun by gravity as needed.*

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into the educational field as well as an account of the SOCIETY's aims and activities.

Mr. Plummer's address on "Large Storage Tanks and Pressure Vessels" encompassed the complete field of design parameters, selection of materials, material sizes, joint design, welding sequence, nondestructive testing and inspection. His talk was illustrated with colored slides depicting the various preparation, welding and inspection operations necessary for these large welded structures.

CHROME-MOLY PIPE

Toledo, Ohio.—the *Toledo* Section's February meeting was devoted to the welding of chrome-moly piping. Charles Dooley, welding engineer for the Sun Shipbuilding & Drydock Co., presented the subject in a very interesting manner. The meeting was one of the highlights of the season in Toledo, because of a large turnout of 80 members and guests, and because of the effectiveness of the speaker in presenting his subject in such an interesting manner.

Mr. Dooley prefaced his talk by pointing out how fortunate most fabricators and repairmen are to have a known material with which to work. Some of the repairs necessary in shipyard work are on foreign vessels and often the type of material to be repaired is difficult to identify.

The speaker covered the subject of chrome-moly welding very thoroughly. He went into detail on joint design. Sun Ship is having some success in making their own ring inserts for first pass welding using the inert-arc gas-shielded process. Mr. Dooley also covered inert atmospheres, inspection, preheat and stress relief and electrode selection.

ULTRASONIC INSPECTION

Thompsonville, Conn.—A meeting of the *Western Massachusetts* Section was held in the Silhouette Restaurant in Thompsonville, Conn. on Feburary 11th.

Technical speaker was John E. Bobbins of the Sperry Products Co., Danbury, Conn., who spoke on the subject "Ultrasonic Inspection of Materials and Weldments," illustrating his talk with slides.

TOOLING FOR WELDING

Grand Rapids, Mich.—The regular monthly meeting of the *Western Michigan* Section was held on Monday evening, January 27th, at the Varsity Grille in Grand Rapids.

There were 55 present for the dinner and coffee talk which was given by James Mudge, staff writer for the Grand Rapids Herald. Mr. Mudge gave the very interesting highlights of being a staff reporter for a daily paper.

The technical session was covered by Cecil C. Peck [AWS], of the Cecil C. Peck Co. of Cleveland. Mr. Peck's talk was on "Tooling for Welding."

His talk was preceded by slides showing some of the various machines his company has built for automatic welding.

The lecture proved to be very interesting, and several stayed to talk over special problems with him.

WELDING STAINLESS STEELS

Worcester, Mass.—The *Worcester* Section met on February 3rd for dinner and meeting at Nick's Grille.

The speaker of the evening was H. F. Reid, Jr. [AWS], manager, Technical Service Division, the McKay Co., Pittsburgh, Pa. His subject was "Welding of Stainless Steels." In developing this subject he took each branch—martensitic, ferritic and austenitic and described the metallurgical properties of each. Then he dealt with the methods and wires, which must of necessity be used to join these fifty-odd varieties of stainless steels by the arc-welding process. Processes are continually being developed and, at the moment, a half dozen are available and in general use.

Mr. Reid described each group of alloys in considerable detail, their strength, corrosion resistance, finish, purpose and generally recommended usage. In addition to the regularly used and better-known alloys, he gave an insight into the high-chrome alloys, as well as a bit of advice regarding usage of the chrome-manganese group.

Slides were used to show how the coatings were applied to the rods, as well as a thumbnail sketch of the chemical content of a number of coatings.

Mr. Reid was congratulated on presenting the clearest and most informative lecture this group had listened to in some time.

WELDING CLAD STEELS

Grand Rapids, Mich.—The February meeting of the *Western Michigan* Section was held on Monday evening, February 24th at the Varsity Grille in Grand Rapids.

There were sixty-seven present for the dinner who were joined later by five more for the coffee talk and technical session.

E. R. Post, principal of the Grand Rapids Christian High School, gave a very humorous talk on teen-agers. Mr. Post has had thirty years experience with students.

The technical session was covered by A. W. Schueler, chief development engineer of the Precision Welder & Flexopress Corp. of Cincinnati, Ohio.

Mr. Schueler talked on the welding of Vinyl clad steel and told of his company's experimental work in developing a process to weld the clad steels. Several companies from the area sent their men to this meeting as they are experimenting with clad steels for several new products.

All agreed that this had been a very enlightening and interesting meeting.

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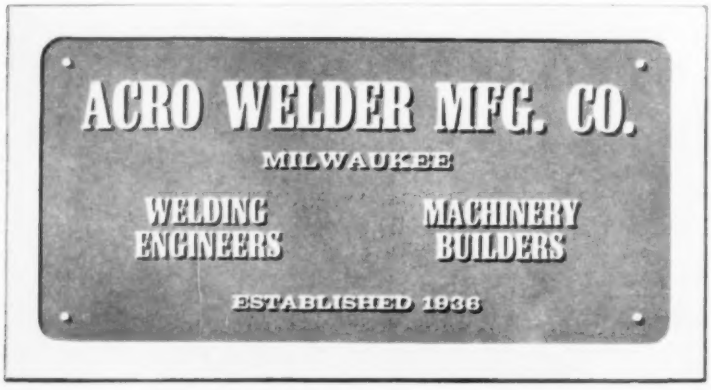

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D—Student Member E—Honorary Member F—Life Member

Total National Membership

Sustaining Members	*178*
Members	*6,070*
Associate Members	*6,021*
Student Members	*187*
Honorary Members	*9*
Life Members	*15*
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Weiss, Jerry L. (C)

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Oehler, Edward A. (C)

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Schaack, Nicholas J. (B)

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Gott, George S. (C)
Klingensmith, Karl K. (C)
Voloschin, Norberto (C)

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Goldstein, Philip (C)
Graham, John M. (B)
Joseph, E. Earl (C)
Klug, Alex (C)
McCliesh, James (B)
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Yelito, Stanley J. (C)

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Poole, Edward A. (B)

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Davison, Collins Perry (C)

ROCHESTER

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Miner, Emerson (C)

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Von Tiekner, B. P. (C)

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Rull, Loren (B)

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Kindred, Carl B. (B)
Muetzenberg, William J. (B)
Wilson, Emmett O. (B)

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Stone, Howard A., Jr. (B)

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Meekly, Richard W. (C)
Stehman, George O. (B)

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Metzka, Andrew (B)
Putnam, Doy V. (B)

Rodrigues, Jose Eduardo Pereira (C)
White, Albert A. (B)

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Rinkus, Donald M. (D to C)

CLEVELAND

Pocker, Richard L. (C to B)

HOUSTON

Williams, J. C., Jr. (C to B)

LOS ANGELES

Binder, R. W. (C to B)
Hayes, Richard C. (C to B)
Lord, Cecil F. (C to B)

MILWAUKEE

Sommerfeld, Robert C. (C to B)

NIAGARA FRONTIER

Arnold, Dale (C to B)

NORTHERN NEW YORK

Allio, Robert J. (D to C)

PHILADELPHIA

Boyer, Thomas H., Sr. (C to B)

ROCHESTER

Beachner, James N. (C to B)

SAINT LOUIS

Ryan, Thomas J., Jr. (C to B)
Wulfert, Otto (C to B)

STARK CENTRAL

Edwards, Walter Rex (C to B)

TOLEDO

Morrison, Warren D. (C to B)

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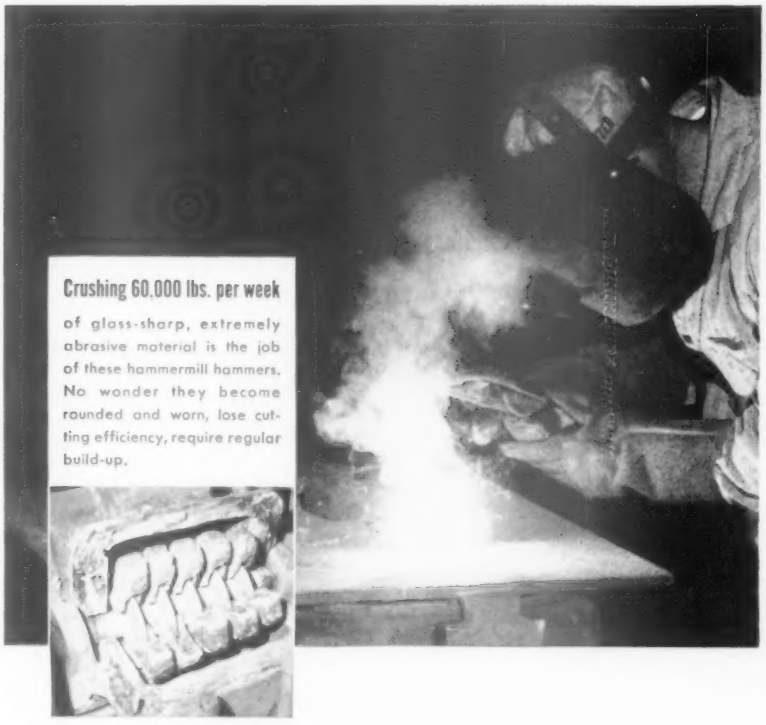
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ABSTRACTS OF CURRENT PATENTS

prepared by Vern L. Oldham

Printed copies of patents may be obtained for 25c from the Commissioner of Patents, Washington, D. C.

2,805,321—Electrical Welder for Upright Seams—Ralph K. Cadwell, Los Angeles, Calif., assignor to Lacy Manufacturing Co., Los Angeles, Calif., a corporation of California.

Cadwell's patent is on an automatic welder for welding an upright joint between the edges of upright plates. The welder includes a support having upright guide means and a carriage movable along the upright plates. The apparatus includes other special portions including a belt member for holding flux in a position to shield the welding arc as welding action occurs.

2,805,322—Apparatus for Forming Protuberances on Stamping Tools—Charles E. Phillips and Peter N. Frade, Detroit, Mich., said Frade assignor to said Phillips; Charles A. Dean, executor of said Charles E. Phillips, deceased.

This patent on a welding tool relates to a tool having means for holding it in fixed registration with the work and a consumable electrode is carried by the tool. Other means connect the tool and the work in an electric circuit and the electrode is contacted with the work to form an arc that will be automatically extinguished when drawn to a predetermined length by consumption of the electrode. A manually operable resilient member is mounted on the tool and engages the electrode to advance it for initial contact with the work.

2,805,971—Welding Flux—Henry B. Bryan, Troy, Ohio, assignor to the Hobart Brothers Co., Troy, Ohio, a corporation of Ohio.

Bryan's patented welding flux is for use in arc welding and is primarily composed of rutile, silica sand, marble and an alkali metal silicate binder selected from the group consisting of glass cullet and sodium silicate.

2,806,124—Arc Torch and Process—Robert M. Gage, Buffalo, N. Y., assignor to Union Carbide Corp., a corporation of New York.

This patent relates to a process comprised of and establishing a high-pressure arc between an electrode and a workpiece and wall-stabilizing a portion of the length of such arc to produce and control the shape and direction of an effluent between the point of wall-stabilization and the workpiece. Then the so-controlled effluent is applied to the workpiece. The patent also discloses apparatus for practicing this process.

2,806,125—Welding Gun—Joseph F. Miller, East Amherst, N. Y., assignor to Westinghouse Electric Corp., East Pittsburgh, Pa., a corporation of Pennsylvania.

Miller's patent upon an arc welding gun is for use with a consumable electrode. The gun has a barrel terminating in a gas nozzle. Means are provided for transmitting cooling fluid to and away from the nozzle whereas other means are provided to transmit a shielding gas through the nozzle.

2,806,126—Arc-Welding Apparatus—Lawrence C. Gladen, Willoughby, Ohio, assignor to General Motors Corp., Detroit, Mich., a corporation of Delaware.

The present patent relates to a combination of a pair of separate and distinct welding electrodes each having its own separate insulating flux coating over a central core. An electrode holder is provided and is connected to a source of electrical power and holds the electrodes by skinned end portions thereof. The holder secures the electrodes in tension against each other with the insulated coatings of the electrodes touching over the major portion of their lengths.

2,806,127—Electric Arc Welding—Robert L. Hackman, Morris Plains, Roscoe R. Loboseo, Fanwood, and Wilbur Herman Helmbrecht, Union, N. J., assignors to Union Carbide Corp., a corporation of New York.

This invention relates to electric arc welding wherein a consumable continuous metal electrode is fed toward the work to establish and maintain a welding arc therewith. The patent teaches the use of a power source having dynamic volt-ampere characteristics such that the output voltage delivered to the arc does not decrease substantially with increasing output current in the usable current range. Initially the electrode is fed to the work at a feed rate less than normal to initiate a weld arc and burn the electrode back to approximately full electrode cross section. Then the electrode feed is accelerated to a predetermined normal feeding rate and such normal feeding rate is maintained until the welding action is completed.

2,806,128—Welding Electrode—Albert Muller, Watchung, N. J., assignor to Air Reduction Co., Inc., New York, N. Y., a corporation of New York.

Muller's patent relates to an arc-welding electrode made from a plurality of wire strands forming a unitary electrode structure having an electrically conductive outer surface for making electrical contact with a current feeding source. In the wire strands forming the electrode, a metal selected from the group consisting of the alkali metals, the alkaline earth metals, the lanthanum and the lanthanum series rare earth metals and the actinium series rare earth metals is included. At least one of the wire strands is free from such specified metal substances.

2,806,129—Tungsten Carbide Weld Rods—Arthur T. Cape, Los Angeles, Calif., assignor to Coast Metals, Inc., Little Ferry, N. J., a corporation of Delaware.

A weld rod for hard surfacing and the like action is disclosed in the patent. The rod includes a ferrous tube containing particles of tungsten carbide as a filler, together with particles of copper. The copper comprises about 1 to 10% by weight of the filled tube.

2,806,168—Welding Control System—William F. Williams, Flint, Mich., assignor to General Motors Corp., Detroit, Mich., a corporation of Delaware.

This patent upon a control system for a welding machine relates to an apparatus having a source of welding power, a source of generated power for control, and feeding means for the electrode wire connected in a series circuit with both sources and operated by the algebraic sum of the voltages thereof. A resistance is provided in this series circuit and other means are present to include or remove the resistance operated by the flow of welding current. The resistance means is included when the welding current is below a minimum value.

2,806,345—Machine for Trimming Weld Flash from Chain Links—Earl K. Phares, Hammond, Ind., assignor to S. G. Taylor Chain Co., Hammond, Ind., a corporation of Illinois.

The patented machine provides a special apparatus for trimming welding flanges from a welded link at the end of a length of chain.

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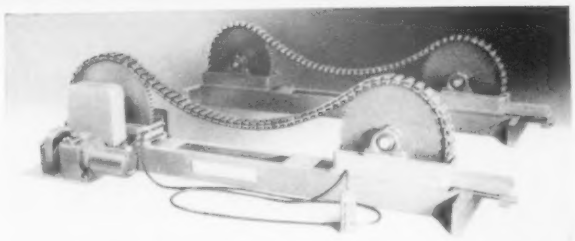

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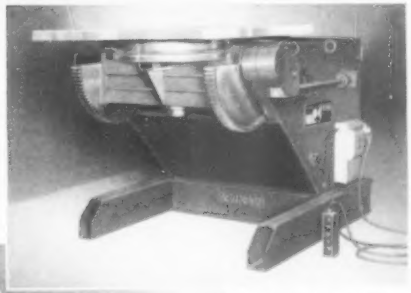

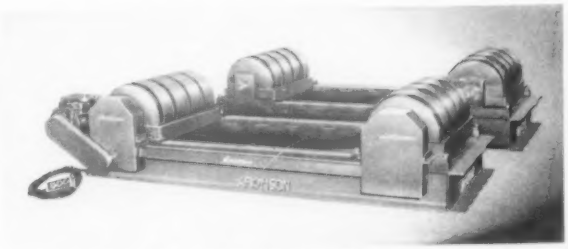

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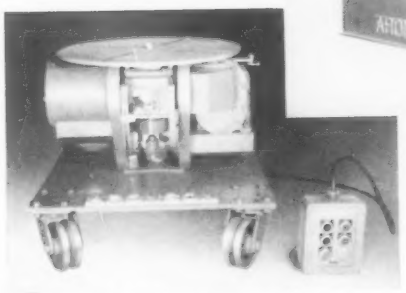

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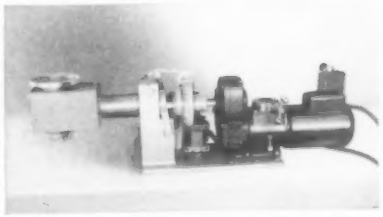

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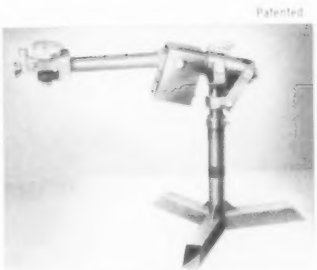

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and in Booth 626 at the South Western Metal Exposition—Dallas, Texas—May 12 to 16

For more details, circle No. 18 on Reader Information Card

NEWS of The Industry

Kaiser Steel Names Cutler and Collin

Two recent engineering appointments at Kaiser Steel Corp., Montebello, Calif., involve Ralph W. Cutler and A. L. Collin.

Mr. Cutler has been named manager

Ralph W. Cutler

of engineering and estimating in the fabricating division plant. Prior to joining Kaiser, he was an engineering consultant. Mr. Cutler is a member of the AMERICAN WELDING SOCIETY, Tau Beta Pi, Sigma Xi, American Society of Civil Engineers and Structural Engineers Association of Southern California, in addition to being a registered civil, structural and mechanical engineer with the state of California.

At the same time A. L. Collin was appointed chief development engineer at the Kaiser plant. Mr. Collin was formerly manager of engineering at the Montebello plant. A member of the AMERICAN WELDING SOCIETY, Mr. Collin is also a member of the American Society of Civil Engineers, American Ordnance Assn., Chi Epsilon and the Structural Engineers Association of Southern California.

A. L. Collin

Canadian Welding Seminar

The National Executive of the Canadian Welding Society has announced their plans to co-sponsor, with the Department of University Extension of the University of Toronto, a National Welding Seminar to be held in the Wallberg Memorial Building, University of Toronto, on and between June 2 to June 6, 1958.

The seminar, patterned after a similar summer course of the British Welding Research Assn., is designed to bring the latest technological improvements to the attention of the engineers and technicians of the industry.

Dr. W. C. Winegard, associate professor, Department of Metallurgical Engineering, will be course director, assisted by an Education Sub-Committee of the Welding Society organized by W. A. Martin, research metallurgist of the Hydro-Electric Power Commission of Ontario.

The Seminar Course has been prepared in lecture and discussion sessions starting on Monday, June 2nd, and continuing through until mid-day of Friday, June 6th.

Residence may be arranged in the university buildings and informal evening talks among groups of course members will be arranged at the university residence.

Each day of the seminar will feature a particular field of welding technology; for example: Monday "Metallurgy," Tuesday "Design for Welding," Wednesday "Materials for Welding," Thursday "Welding Costs" and, finally, "Code Regulations, Procedure Qualification and Inspection."

Throughout each day's session, considerable attention will be directed to the field of cost improvement as this is a decisive factor in modern technology.

These subjects will be covered by a total of 18 lecturers selected from Canadian and American industry and universities for their leadership in a specific field of knowledge.

Airco Earnings Hit New High

Air Reduction Co., Inc., sales and earnings reached record highs in 1957, John A. Hill, president, announced recently.

Sales in 1957 were $189,987,698, an increase of 12% over 1956 sales of $169,818,703, the previous all-time high. Net income for 1957 was $16,476,180 or about 5% higher than 1956 net income of $15,731,579, also the previous record.

M & T Declares Dividends

Directors of Metal & Thermit Corp., at their regular meeting, declared the regular quarterly divided of 30¢ per share on the common stock, it was announced by H. E. Martin, president.

The dividend was payable Mar. 17, 1958 to shareholders of record at the close of business on Mar. 7, 1958.

The directors also declared the regular quarterly dividend of 87½¢ per share on the preferred stock, payable March 28, 1958 to stockholders of record at the close of business on Mar. 18, 1958.

Control of Crescent Company Reacquired

Milton C. Sapinsley, founder of the Crescent Co., manufacturers of insulated wire and cable of Pawtucket, R. I., and his son John M. Sapinsley, have contracted to reacquire control of the company which they sold to Penn-Texas Corp. in 1953.

The company was established in 1920 and expanded from automotive and radio wire and cable into a complete line of electrical, electronic, automotive, welding and mining machine cable. It

COMING EVENTS

A Calendar of Welding Activity

AWS National Meetings

1959 Spring Meeting and Welding Show:
April 6-10, Sherman Hotel, Chicago, Illinois

NWSA

May 5-8. 14th Annual Convention. Americana, Miami Beach, Fla.

For more details, circle No. 19 on Reader Information Card →

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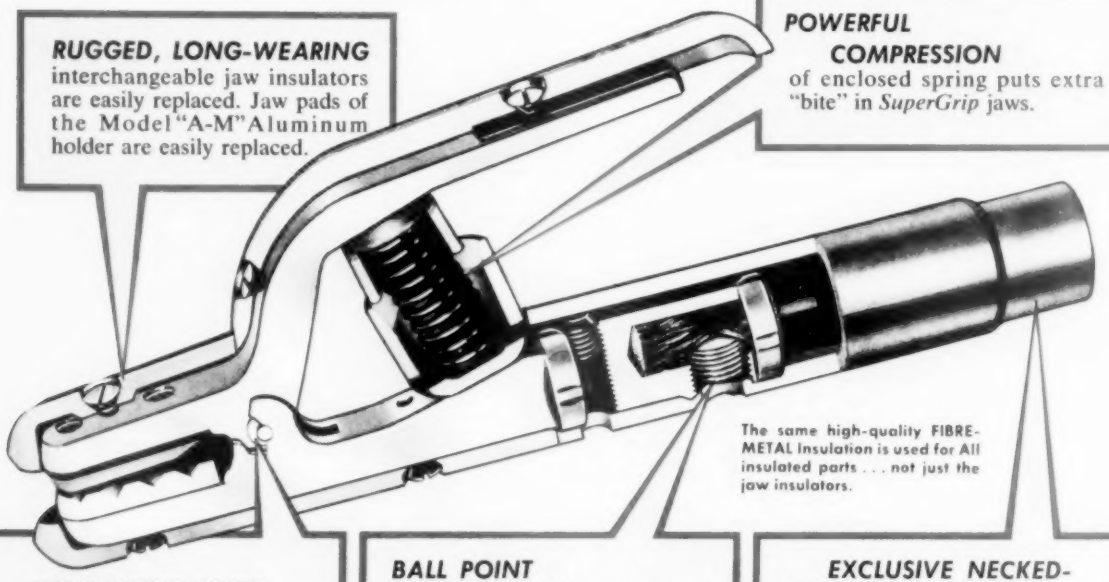

RUGGED, LONG-WEARING interchangeable jaw insulators are easily replaced. Jaw pads of the Model "A-M" Aluminum holder are easily replaced.

POWERFUL COMPRESSION of enclosed spring puts extra "bite" in *SuperGrip* jaws.

The same high-quality FIBRE-METAL Insulation is used for All insulated parts . . . not just the jaw insulators.

PERMANENT PIVOT BUSHING in tongue of trigger assures alignment, minimizes wear and increases service life of the Model "A-M" Aluminum holder for lowest cost.

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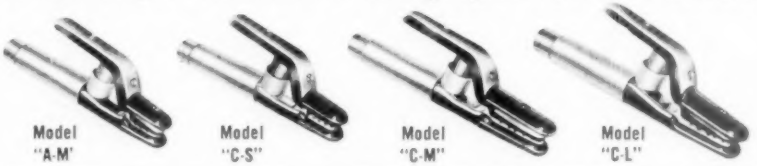
EXCLUSIVE NECKED-DOWN HANDLE cuts "cable fatigue" by reducing cable play at handle end and close to the cable connection . . . to effectively prevent fraying and fatigue of wire strands.

SuperGrip*™** is *the* Welding Electrode Holder designed to eliminate not just one or two, *but EVERY* awkward, irritating, troublesome design point ever built into an ordinary electrode holder! No more frayed cables! No more overheated holders! ***Now you get the neat, compact design that increases maneuverability and minimizes welding work fatigue!

At every vital point . . . bushed pivot pin, long-wearing jaw surfaces, powerful spring, securely anchored cable, reduced cable play . . . *SuperGrip* approaches the ultimate in Welding Electrode Holder design. *Ask your welding distributor for a SuperGrip today!*

4 *SuperGrip*™ *Models cover the complete range of normally-encountered welding operations and currents:*



Model	Material	Capacity	Max. Electrode Dia.
"A-M"	Aluminum	300 Amps.	1/4"
"C-S"	Copper Alloy	250 Amps.	7/32"
"C-M"	Copper Alloy	300 Amps.	1/4"
"C-L"	Copper Alloy	500 Amps.	3/8"

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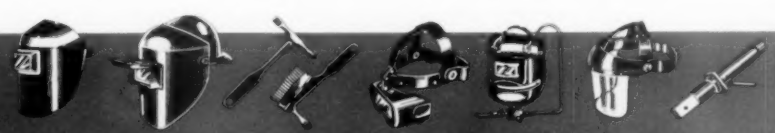

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operates the Lowell, Mass., Division as well as the Carol Cable Division.

Milton C. Sapinsley is chairman and treasurer, and John M. Sapinsley is president, posts which they held prior to the sale to Penn-Texas and also during the period when the company stock was owned by Penn-Texas Corp.

Harris Calorific Forms Australian Subsidiary

C. M. Taylor, president of Harris Calorific Co., 5501 Cass Av., Cleveland, has announced the formation of a new company in Australia, known as Harris Calorific Ltd. The organization will make its headquarters in Melbourne and will manufacture the complete line of Harris gas welding and cutting torches, tips and regulators.

Distribution of Harris products will be made through a number of distributors, one of the most important being the Industrial Oxygen Co., a newly formed subsidiary of Industrial Engineering Co., large and diversified family of related enterprise headed by Lance E. H. Reichstein, chairman of the board. Distributors are being established in all areas of Australia. George Ellis, for 15 years associated with British Oxygen Ltd., will be general manager.

Goodrich Elects

Goodrich Welding Equipment Corp., Hudsonville, Mich., announced the following appointments and promotions: J. C. Girod became chairman of the board. Arend Bruinsma was named president, William F. Qualls was appointed general manager and Robert C. De Young was named secretary-treasurer of the corporation. Mr. Qualls is a member of the AMERICAN WELDING SOCIETY.

J. C. Girod

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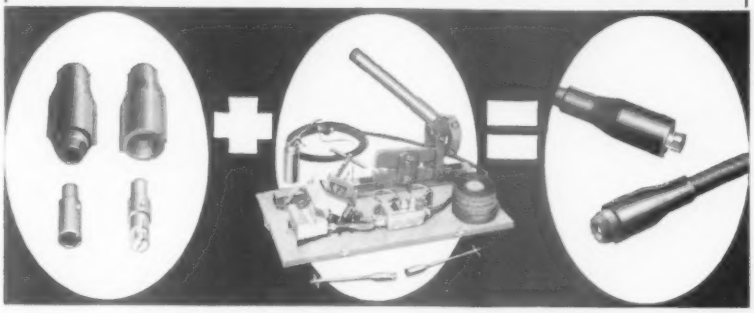
. . . the smoothest connection you can make!



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No more bulky cable connections to "foul up" on obstructions and delay production. Now you can make shockproof, waterproof cable connections in your own plant in minutes with a 110 volt portable Vulcanizing Kit. Seals prefabricated neoprene insulating sleeves to cable jackets. . . cable breakage at connector is eliminated. . . cable jackets cannot pull away. Connectors lock tight —stay tight! Join all cable sizes instantly without adaptors.

Write for free catalog and see how simple, convenient and foolproof these connectors are to use. Vulcanizing Kit can also be used with an adaptor mold to make neoprene insulated, waterproof *Cable Splices!*

Visit our booth #704 at the American Welding Society Convention, April 14 thru 18, Kiel Auditorium, St. Louis, Mo.

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Orrweld Appoints Leaman, Dorrell and King

Orrweld, Inc., division of William M. Orr Co., Inc., Pittsburgh, Pa., announces several appointments within its organization.

Gerry Leaman, formerly Western

Gerry Leaman

New York District sales manager of the Welding Equipment Division of General Electric Co., has been appointed Buffalo district sales engineer. A member of the board of directors of the Niagara Frontier Section, Mr Leaman is also chairman of National Committee "A"

Fred Dorrell

Robert King

of the Educational Activities Committee.

Fred Dorrell also joins Orrweld as general manager of welding supplies and equipment. He was previously welding division manager of the southeastern states for General Electric Co.

At the same time it was announced that Robert King had been appointed sales engineer for welding service for the Ohio and West Virginia areas. Mr. King was formerly an electric welding specialist with the General Electric Co.

The Messrs. Leaman, Dorrell and King are members of the AMERICAN WELDING SOCIETY.

Resistance-Welding Film

The Resistance Welder Manufacturers' Association has released a new film, "Resistance Welding," which has just been completed and is available to the public on a loan basis, at no charge.

It has been produced to furnish each welding user, prospective user and individuals interested in welding with the most up-to-date information possible about available resistance-welding equipment and some of the jobs such machinery can do. Applications range from the simplest to the most complicated and complex automated lines.

This motion picture, which is 23 minutes in length, 16 mm, in color and optical sound, follows in logical sequence the General Electric Co. movie, "This is Resistance Welding," which can also be obtained through RWMA.

"Resistance Welding" is available to industry, societies, technical organizations and universities and schools. Your request should be directed to the Resistance Welder Manufacturers' Association, 1900 Arch St., Philadelphia 3, Pa.

Swain Awarded Morehead Medal

Robert C. Swain, vice-president in charge of research and development, American Cyanamid Co., received the James Turner Morehead Medal for 1957 at the convention of the International Acetylene Association in the Bellevue-Stratford Hotel, Philadelphia, Pa., on March 19th to 21st.

The Morehead Medal was awarded to Dr. Swain for "leadership in developing a commercial process for melamine and related derivatives of calcium carbide." Dr. Swain guided the research team which developed a practical process for melamine resins, out of which entire new industries have grown.

Beginning as a research chemist with American Cyanamid in 1934, Dr. Swain went to the Stamford, Conn. laboratories in 1936 where he met the challenge of

Rene D. Wasserman, President, Eutectic Welding Alloys Corporation commends to industry:

Our first line of defense...

...is our faith in God...the inner peace that only worship brings.

National Sunday School Week, April 14 through April 20, is sponsored by the Laymen's National Committee, an All Faiths organization.

Moral faith is the basis of our society. Instilling this faith in our children is our assurance that our way of life will endure.

Laymen's National Committee, Inc., Hotel Manger-Vanderbilt, N.Y. 16, N.Y.

NATIONAL SUNDAY SCHOOL WEEK—APRIL 14-20

This advertisement contributed by:

ORIGINAL Low Temperature EUTECTIC WELDING ALLOYS

melamine. In 1942 he became director of the Stamford laboratories and in 1945 he was promoted to director of research for American Cyanamid. The following year he was elected a vice-president in charge of research and development and a director of the company.

Today the innumerable users of melamine products, whether they be unbreakable dishes, gleaming Formica panels or molded electronic parts, are probably not aware that these items began as lumps of calcium carbide.

Dr. Swain is a graduate of Stanford University in California. He took his Ph.D. as an Alexander von Humboldt fellow, studying at the University of Heidelberg and the University of Berlin.

NACE Elects Bladholm

E. F. Bladholm, senior mechanical engineer of Southern California Edison Co., has been elected western region chairman of the National Association of Corrosion Engineers for 1958.

Consisting of 5000 engineers from industries throughout the United States, the association concerns itself with research into the causes of the various forms of corrosion which are estimated to cost U. S. industry in excess of $5\frac{1}{2}$ billion annually.

E. F. Bladholm

Mr. Bladholm, the new western region chairman, is also a member of the AMERICAN WELDING SOCIETY, the Pacific Coast Electrical Assn. and the Los Angeles Electric Club.

Technical-Writing Seminar

Eight technical-writing authorities from national business and industry will survey all phases of technical communication at the 6th Annual Technical Writers' Institute to be conducted at Rensselaer Polytechnic Institute, Troy, N. Y., June 9-13, 1958. The week-long workshop, directed by Prof. Jay R. Gould, will be staffed by nine lecturers from Rensselaer's faculty in language and literature.

The attending group will be divided according to interest and specialization. Sessions will be conducted on report writing, manual and instruction book writing, technical sales writing, the preparation and publication of magazine articles and technical illustration.

AGA Announces Convention Site

The American Gas Association, stressing the dynamic growth of the gas industry and its important contributions to the nation's economy, has chosen "Gas Builds A Greater America" as the theme of its 40th annual convention to be held next October 13-15 in Atlantic City, N. J.

New Brazing Firm

The opening of a new company specializing in the manufacture of alloys and fluxes for brazing has been announced. American Brazing Alloys Co., P. O. Box 11, Pelham, N. Y., has opened the doors to the Ambraze line. The products will be sold only through distributors, with no sales to direct users.

Ambraze alloys will reportedly meet all government, AWS and ASTM specifications.

Mike Ross, former owner of Zaudcer Associates and former public relations director of Bassons Industries, will head the sales program.

CGA Elects Officers

A. R. Olson, Suburban Propane Gas Co., Whippany, N. J., was elected president of the Compressed Gas Assn., Inc., at the Associations' 45th Annual Meeting held January 20-22 in the Waldorf-

A. R. Olson

Astoria Hotel, New York City. Other new officers include Claude E. Monlux, Linde Co., Division of Union Carbide Corp., New York, 1st vice-president, and George C. Cusack, Pure Carbonic Co., a Division of Air Reduction Co., Inc., New York, 2nd vice-president. Franklin R. Fetherston was re-elected secretary-treasurer.

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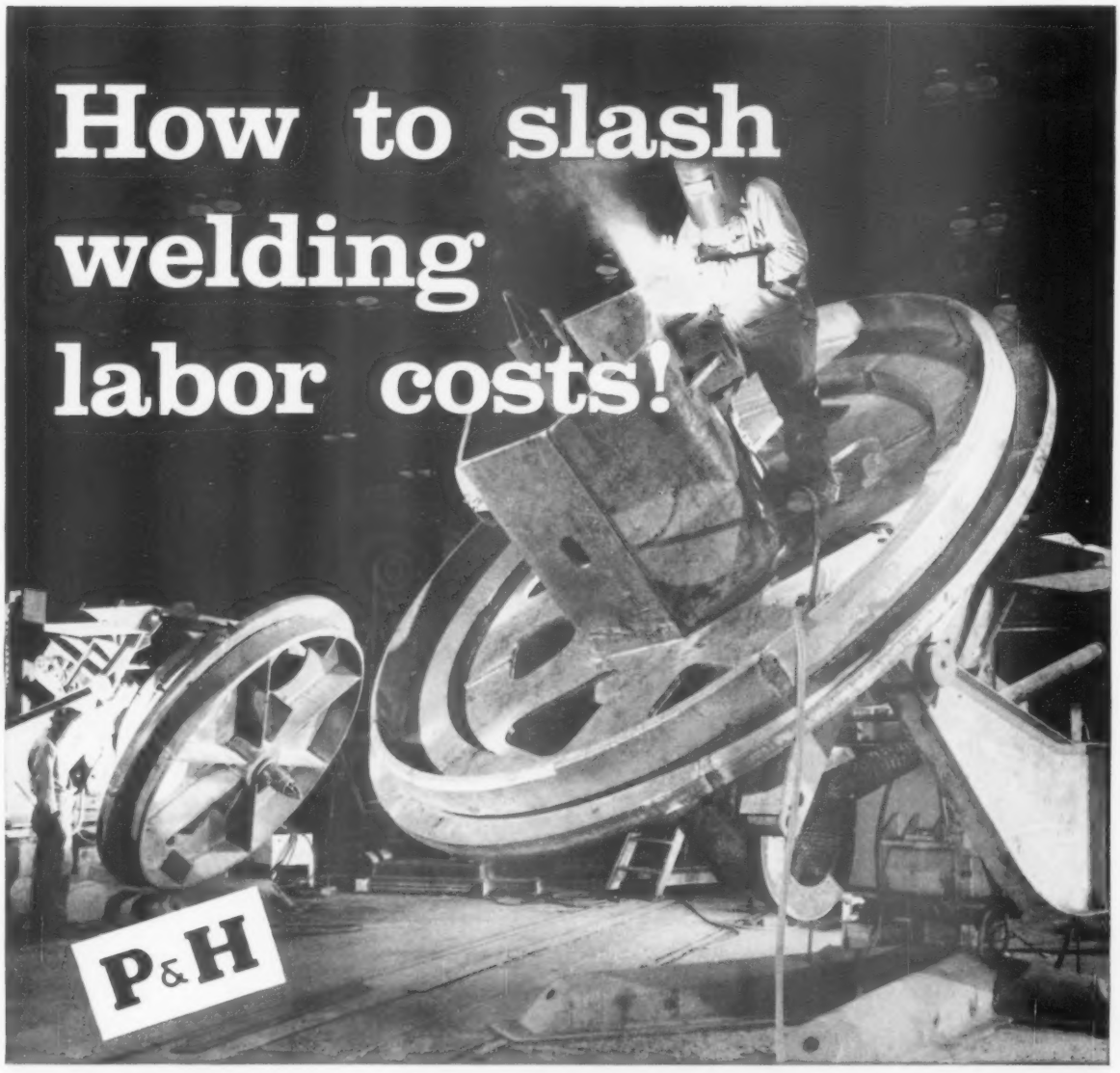

Mechanize your weldment handling with P&H Welding Positioners

P&H Welding Positioners can often cut labor costs in half by providing faster, safer, *mechanized* weldment handling. With these modern machines, operators merely press a button to quickly spot the work so that all welds are made downhand — in the natural position.

Downhand welding pools more evenly, permits the use of larger, "hotter" rods — frequently cuts the number of passes from 3 to 1.

As a result, you get more arc-time *plus* better welds. Your weldors turn out more work each day and like it — they don't have to work in cramped, awkward positions that reduce efficiency. You eliminate waiting for cranes, and the use of extra helpers for repeated repositioning.

These money-saving machines are available from P&H with full 360° table rotation, 135° tilt, and power elevation even under capacity loads. (500 to 100,000 pound capacities.) Write today for "What You Should Know About Welding Positioners." Address Dept. 305U, Harnischfeger Corp., Milwaukee 46, Wisconsin.

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P&H WELDERS • ELECTRODES • POSITIONERS

For more details, circle No. 23 on Reader Information Card

VICTOR EXECUTIVES BREAK GROUND FOR NEW ADDITION

Shown (*left to right*), at a recent groundbreaking ceremony at Victor Equipment Co., 844 Folsom St., San Francisco, Calif., are E. A. Daniels, vice-president in charge of sales; R. R. Zimmer, chief engineer; F. L. Settner, plant manager; and L. W. Stettner, president; Ceremony marked construction of a 10,000-sq ft two-story addition adjoining the present plant site

ASME Appoints Schier

O. B. Schier, II, has been appointed secretary of the American Society of Mechanical Engineers. Mr. Schier, who was designated secretary-elect last June, succeeds Clarence E. Davies who was secretary of ASME for 23 years.

Metallurgy Conference

The Gordon Research Conference on physical metallurgy will be held during June 9th to 13th, 1958, at the New Hampton School, New Hampton, N. H. The conference will investigate "Microstructures: Their Origin and Influence on Properties." Separate sessions will examine special techniques, dislocations studies, precipitation and second phases, deformation and fracture and oxidation and corrosion.

Additional information can be obtained by writing W. George Parks, director, department of chemistry, University of Rhode Island, Kingston, R. I.

Increase Service Life of Tractors!

Reclaim WORN TRACTOR PARTS with MANGANAL

11¾-13½% MANGANESE-NICKEL STEEL

APPLICATOR BARS & WELDING ELECTRODES

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- Work harden to 550 Brinell
- Tensile strength up to 150,000 psi
- Outlast new parts

Write for How-to-do-it Bulletin and name of nearest distributor

MEMBER

STULZ-SICKLES CO.

PORT AVENUE at JULIA ST. ELIZABETH, NEW JERSEY

For more details, circle No. 24 on Reader Information Card

GIFT FOR ARIZONA STATE COLLEGE

Arizona State College at Tempe has received this latest gift of inert-gas welding equipment with self-contained unit affording either a-c or d-c from Tec Torch Co., Carlstadt, N. J., and Hobart Bros. Mfg. Co., Troy, N. Y. Photographed at presentation were (*left, standing*): Gil Dye and Gil Dye, Jr., of Dye Oxygen Co., and Phoenix Welding Supply Co., Phoenix, Ariz., distributors; and Marlow Keith, ASC assistant professor of technology; (*kneeling, from left*): Steve Meehan, welding engineer, and Dr. W. E. Burdette, head of the ASC division of technology

DISTRIBUTORS WIN HOBART AWARDS

"Quotabusters" award for 1957 is presented to Virginia Welding Supply Co., 114 Virginia St. East, Charleston, W. Va., by W. H. Hobart, vice-president of Hobart Brothers Co. On the right is Bill Rice, sales manager of Virginia Welding, receiving the award

Volume award for 1957 is presented to Wolfenden Welding Supplies, Inc., 3500 Prospect Ave., Cleveland, Ohio, by W. H. Hobart, vice-president of Hobart Brothers Co. (*Left to right*) Mr. Hobart, Bill Wolfenden and John T. Wolfenden, Jr.

HONORED BY DOCKSON

At a recent celebration of the Dockson Corp., Detroit, Mich., the company marked its 35th anniversary with the presentation of service awards to its employees. Among the recipients of awards were (*left to right*) Charles W. Piggott, vice-president, 25 years; Harold E. Piggott, president, 35 years; and Joseph Kramer, development engineer, 25 years

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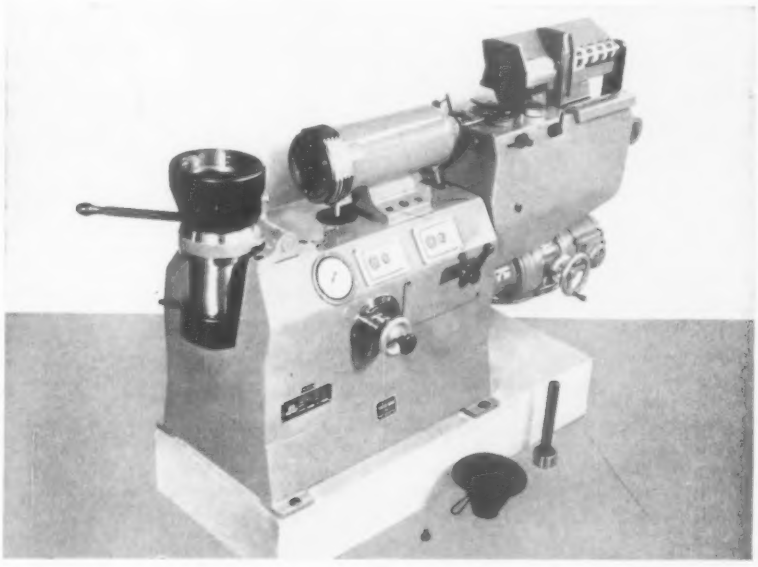

One example out of our production programme:
OERLIKON EP 12 EXPERIMENTAL EXTRUDER
Wire speed 15-105 ft.—min. Rod length 8-20 in.
Wire gauges 1/32-13/32 in. Flux volume 27 cu. in. or 40

For detailed information please write to:

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BUEHRLE & CO.

Welding Electrode Division

Zürich-Oerlikon, Birchstrasse 230, Switzerland

For more details, circle No. 25 on Reader Information Card

INTERNATIONAL WELDING NEWS

By Dr. Gerard E. Claussen

CONFERENCES

Wetting and Spreading Discussed in England

A conference[1] on the wetting and spreading of liquid metals on solid surfaces was held in England during the latter part of 1957. Alloying acts to spread a liquid drop after it has first assumed the shape dictated by equilibrium surface tension theory. To prevent excessive solution of the sheet, use a liquid consisting mainly of a metal with limited solubility in the sheet and a small proportion of a more soluble metal. The formation of intermetallic compounds may cause dewetting. One contributor to the conference described the electrolytic welding of a fine wire thermocouple as cathode at 80 to 220 v in 15% sodium carbonate solution in an iron vessel as anode. The atomic hydrogen liberated at the cathode reduces oxides and the heat of recombination ($2H \rightarrow H_2$) fused the wires together.

Meetings Held by Scandinavian Countries

The 1957 Scandinavian Welding Meeting[2] was held in Helsingfors, August 29-31. At the opening session in the auditorium of the Finnish Commercial College, the renowned Sibelius quartet gave a recital. About 300 delegates, from the four Scandinavian countries, attended the conference, which was opened by Mr. H. Branders, chairman of the Finnish Welding Society. He spoke on the welding industry in Finland. Three papers dealt with shipbuilding, including supertankers. Hydrogen in weld metal, the measurement of triaxial stresses, welded design and the arc welding of sheet steel also were discussed. A17-pass arc weld in 1-in. steel plate was found to be in triaxial compression in the center at mid-thickness but to be under biaxial tension just beneath the surface. The last paper at the meeting discussed the economies of automatic welding. On October 7th, representatives of the four Scandinavian countries met in Oslo to celebrate the 25th anniversary of the Norwegian Welding Society. Attending the Jubilee were Otto Forsman, chairman of the Swedish Welding Commission, Gerhard Hansen, chairman of the Danish Welding Society, and K. Raunto, representing the Finnish Welding Society.

Brittle Fracture Problem Important in Russia

Two welding conferences in Russia have been summarized.[3] The Eighth General Leningrad Meeting on developments in welding was held March 25-27, 1957. There were about 70 papers, and the attendance of 274 represented 71 organizations. Some of the subjects covered were fisheyes in welds, crystallization of arc weld metal, argon arc welding of aluminum and titanium and welding distortion. A conference on the effect of shrinkage stresses on the strength of welded structures was held at the Metallurgical Institute of the Russian Academy of Sciences, June 5, 1957, and was attended by 150 representatives of laboratories. Twenty papers were delivered. From the short abstracts given in the magazine it appears that the brittle fracture problem is important in Russia, and that stress relief heat treatment is commonly applied to welded pressure vessels.

RESEARCH

Fisheyes Discussed by Van der Willigen

In the course of a discussion of hydrogen in weld metal, P. C. Van der Willigen[4] describes tests by L. F. Defize in which fisheyes were found in wrought steel. Tensile specimens of rolled mild steel (2 in. gage length, $\frac{3}{8}$ in. diam) were turned smooth, degreased with benzene, heated 1 hour at 570° F to remove hydrogen, and finally were cathodically charged with hydrogen in 10% sulfuric acid containing arsenic. The specimens contained 2.5 ml H_2 per 100 g. The elongation and reduction of area fell from 34 and 66% to 22 and 33%, respectively, after charging. No fisheyes appeared. After reheating 10 minutes at 390° F there was 2.4 ml H_2 per 100 g, the elongation and reduction of area were 27 and 41%, respectively, but eight small fisheyes appeared. Likewise, after 3 days at room temperature, although elongation and reduction of area rose to 30 and 47% and hydrogen fell to 1.2 ml per 100 g, several small fisheyes were observed.

These observations were related to the fibrous structure of rolled steel. The fibrous structure hinders diffusion of hydrogen to form cavities. Reheating or aging at room temperature allows the hydrogen to diffuse to form a high-pressure cavity rather than to remain in dislocations.

Oxygen-Steam Blown Steel Found Satisfactory

The welding qualities of mild steel blown in a converter using a mixture of oxygen and steam (1 oxygen to 1.1-1.5 steam by volume) have been found[5] to be equal to those of steel blown in an oxygen-air converter. Hydrogen absorbed by the steel from the steam during blowing is lost during rolling and so exerts no effect in welding.

Friction Welding and Other Processes Described in Russian Welding Journal

● The September 1957 issue[6] contains a description of equipment for friction welding (p. 19-25). The two surfaces to be joined are pressed together while one of the surfaces is rotated at 3000 rpm. To butt weld two $\frac{3}{4}$-in. bars of mild steel together they are pressed together under a pressure of 4600 psi. When the heat generated at the rubbing surfaces has raised the temperature to the welding point, the pressure is doubled and the rotation is stopped. The total welding time is 10 seconds, and the upset is 0.20 in. For two bars of cast iron $\frac{3}{4}$ in. diam, the pressure is 9200 psi throughout, the welding time is 25 seconds and the upset 0.16 in. For aluminum bars $\frac{3}{4}$ in. in diam, the pressure is 1130 psi, the welding time is 4 seconds, and the upset is 0.12 in. High-carbon steel, stainless steel and brass can also be welded. Two friction-welding machines are available: the smaller for bars of mild steel up to 1.18 in. diam, the larger for bars up to 2 in. diam.

The welds have good tensile and bend properties. The microstructure of the joint shows that the material of the two bars has intermixed. Whereas the energy consumption in flash welding is 245 to 370 kilocalories per sq in. of welded cross section, only 23 to 26 kcal per sq in. is consumed in friction welding.

● Two papers report tests on the strength and toughness of welds at low temperatures. The paper by Sataev (p. 8) shows that the transition temper-

Worn high alloy slurry pump parts, once scrapped, now resurfaced with Inco-Weld "A". . . last longer than new ones!

Now... one electrode... Inco-Weld "A"* handles most problem welds

...joins most dissimilar alloys, too!

The man in the picture is pointing out the resurfaced section on the cover of a stainless steel slurry pump taken from a Chicago refinery.

A year or so ago, pumps like this would have gone to the scrap heap.

Repair by welding did not seem to be practical. A different electrode would have been needed for virtually every job. And if you picked the wrong electrode and cracking developed, you'd have a bigger loss than if the pump were scrapped in the first place.

Today, with Inco-Weld "A" electrode, repair problems like these are a cinch. Weldors at Cimino Machinery Repair Co. get strong, sound, machinable welds using their regular equipment and procedures. Corrosion resistance of the weld deposit presents no problem. Service records show that the repaired pumps last longer than new ones.

Versatile Inco-Weld "A" electrode also gives X-ray quality welds between many dissimilar alloys . . . ferritic and austenitic stainless steels . . . low alloy and mild steels . . . high nickel and other alloys.

New illustrated folder shows where and how you can use Inco-Weld "A" electrode successfully. Contains case histories, useful tips. For your copy of Inco-Weld "A" bulletin, just write Inco.

Inco Rod "A" is now being called Inco-Weld "A". No change in the product.

*Registered trademark

THE INTERNATIONAL NICKEL COMPANY, INC.

67 Wall Street — INCO — New York 5, N. Y.

INCO WELDING PRODUCTS

electrodes • wires • fluxes

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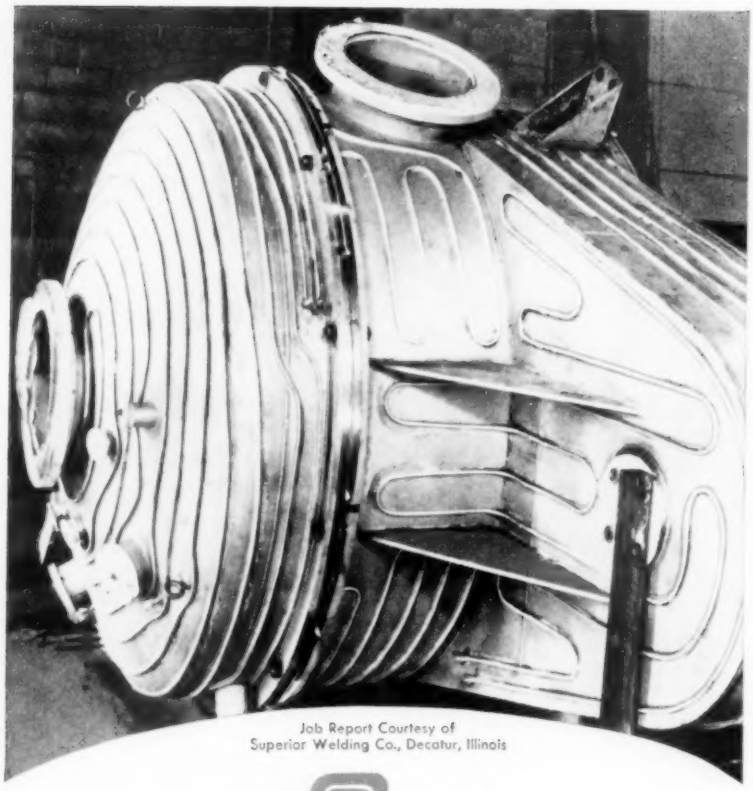
When stainless welds must be VACUUM TIGHT



Job Report Courtesy of
Superior Welding Co., Decatur, Illinois

WELD WITH ARCOS

STAINLESS ELECTRODES

Shown here is a stainless steel furnace body of type 304 ELC for use under very high vacuum conditions in the casting of metals where exceptional purity is required. Arcos Chromend K-LC Stainless Electrodes were used because Arcos electrodes not only assured the proper weld metal chemistry, but also the necessary soundness to insure vacuum tight welds. Save money and future problems with long-lasting Arcos-produced welds. ARCOS CORPORATION, 1500 S. 50th Street, Philadelphia 43, Pa.

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ature for brittle behavior of welded joints in mild steel under static loading rises as the stress concentration is increased. In one series of tests, as the stress concentration factor was raised from 1.0 to 3.5, the transition temperature rose from −112 to −40° F. The paper by Vladimirsky (p. 13) shows the effect of increasing notch sharpness in lowering the impact value and raising the transition temperature of mild steel.

● Two papers deal with resistance welding. An ignitron contactor for slope control is described in one paper (p. 25), while the other (p. 36) describes a condenser discharge welder for the manual spot welding of ferrous and nonferrous metals 0.001 to 0.006 in. thick at the rate of 10 spots per minute.

● A number of papers deal with submerged-arc welding. V. F. Donchenko (p. 27) describes the welding of steel pipe 10 ft diam, up to 2-in. wall, without bevel preparation and with flux backing. Another article (p. 4) describes the surfacing of hollow automotive shafts using an alloy-steel electrode and water cooling inside the shaft. Four articles deal with fluxes. Fluxes have been developed (p. 1) which are claimed to deposit weld metal with unusually low impact transition temperature. The fluxes contain approximately 48% $CaCO_3$, 13% CaF_2, 20% MgO, 5% SiO_2 bonded with sodium silicate to ferro-alloys of manganese, silicon, titanium and aluminum. A total of 3% Ti and Al in the flux produces the best low-temperature impact properties. The addition of iron powder to flux is said (p. 31) to increase the rate of deposition of weld metal. Equipment is illustrated (p. 23 and 29) for grinding and screening flux.

● The transfer of titanium from electrode to weld metal was studied in welding aluminum with covered electrodes (p. 11). With 0.25% Ti in the electrode, the covering of which contained 50% KCl, 35% cryolite, 15% NaCl, 60 to 75% of the titanium was recovered in the weld to act as crack-preventive. The principal factor governing the loss of titanium was the formation of $TiCl_4$ by reaction with flux components. The thicker the covering and the higher the initial percentage of titanium, the lower was the recovery.

BOOKS

Welded Steel Structures

The first of two German books to be described is a small elementary book on welded design for steel structures.[7] The new edition (December 1956) of the German standard DIN 4100 on Welded Steel Buildings, requires the welding engineer or foreman in charge of the manual welding of simple steel structures to attend a course of instruction. This course is given by the Welding Education Division of the German

Welding Society. The book is intended to prepare the student for the course. The book is a rare example of a brief but adequate discussion of structural design requiring no college preparation.

The first half of the book is text, the second half is illustrations in the form of 237 excellent line drawings. The first section covers tension, compression, bending, column action, torsion and shear, and points out ways of utilizing steel to resist each type of stress best. The second section on statics is based on resolution of forces, and explains the engineering principles of trusses, plate girders and frames. The third section deals with the dimensioning of welds and the flow of stress through welded joints. In the last section the problems encountered in welding girders and columns are explained.

Particular emphasis is placed on avoiding notches, and on avoiding welding near the segregated centers of rolled sections. The Krupp version of the ribbed flange for plate girders is recommended. The tapering of the end of flange stiffening plate no longer is recommended. Instead, full width and thickness are maintained to the ends of the plate, but the fillet weld in enlarged to $^3/_8$-in. leg at the ends and is ground smooth.

Collection of Meeting Papers

The second book[8] is a collection of 26 of the papers delivered at the Essen meeting of the German Welding Society on its tenth anniversary, June 25–28, 1957. Most of the papers describe the application of welding to specific products, such as atomic reactors, hydrogen-cooled generators, ships, machine tools, presses, steel buildings, canal gates, cranes, rolling stock, automobiles and pipes. Other papers deal with high-production brazing, flame scarfing, submerged-arc surfacing, welding of plastics and high strength steels, and low-temperture properties of steel weld metal. This is an outstanding book both in quality of text and and in quality of reproduction of the 300 illustrations.

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2. Svetsteknikk, **12**, 81–88, 91–96 (November 1957).
3. Svarochnoe Proizvodstvo, No. 9, 44–49 (September 1957).
4. Van der Willigen, P. C., Schweissen und Schneiden, **9**, 517–521 (1957).
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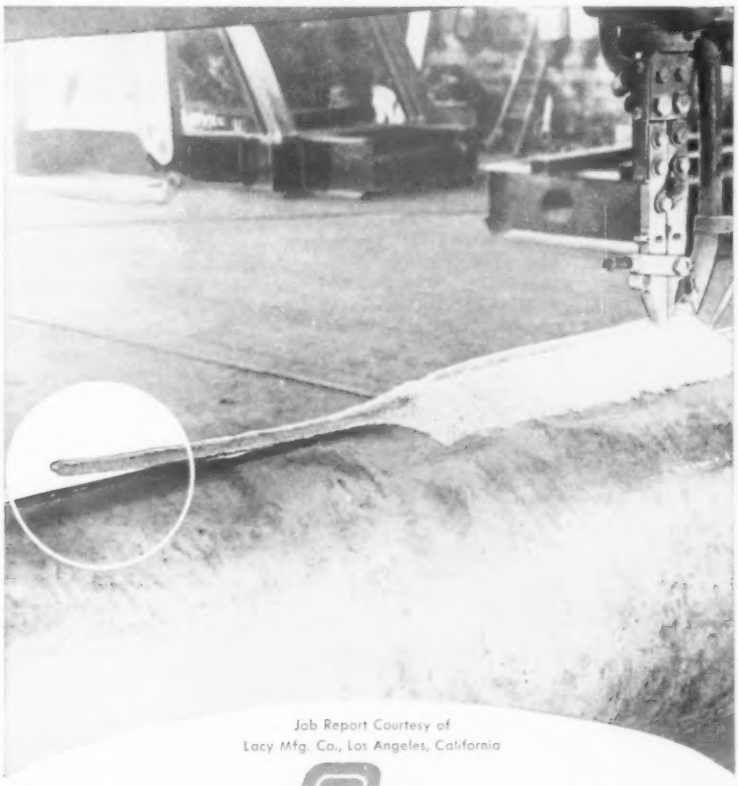
6. Ernger, A., and Schmidtmann, E., Stahl u. Eisen, **77**, 1868–1873 (1957).
7. Sahmel, P., "Schweisstechnische Gestaltung in Stahlbau," Fried. Vieweg & Sohn, Braunschweig, 84 pp. (1957) 6.80 marks.
8. Steigerung der Wirtschaftlichkeit und der Produktivität durch die Schweisstechnik, Fried. Vieweg & Sohn, Braunschweig, 148 pp. (1957), 15.80 marks.

Now, submerged arc stainless welds with slag that "pops-off"



Job Report Courtesy of
Lacy Mfg. Co., Los Angeles, California

WELD WITH ARCOS

Stainless Wire and Arcosite Flux

Arcos research and experience with stainless weld metal now pays you *another dividend*—for the first time . . . consistently *self removing slag!* On the job above, submerged arc welding of a section of pipe for petroleum equipment, two passes were made with $^1/_8$" coiled CHROMENAR KMo Stainless Wire and ARCOSITE S-4 Flux. As the photo shows, the cooling slag is lifting free by itself . . . leaving a clean, smooth bead. Think what this can mean to you on your own submerged arc welding jobs . . . saving time and money . . . better welds than ever before. ARCOS CORPORATION, 1500 S. 50th St., Philadelphia 43, Pa.

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PERSONNEL

Kinzel Elected by AIME

The American Institute of Mining, Metallurgical, and Petroleum Engineers has announced the election of Dr. Augustus B. Kinzel as AIME's president for 1958.

Dr. Kinzel, who is vice-president of Union Carbide Corp., will succeed Grover J. Holt, of Ishpeming, Mich., assistant to the president of the Cleveland Cliffs Iron Co. During the past year, Dr. Kinzel has held the offices of president-elect and director in AIME. He also has been a vice-president of AIME and formerly was chairman of its Finance Committee. He was Howe Memorial Lecturer in 1952.

Dr. Kinzel was born in New York

Augustus B. Kinzel

City. He received a Bachelor of Arts degree cum laude in mathematics from Columbia University, a Bachelor of Science degree in engineering from Massachusetts Institute of Technology, the degree of Docteur of Science from the University of Nancy in France, an honorary degree of Doctor of Engineering from New York University and an honorary degree of Doctor of Science from Clarkson College.

Dr. Kinzel has been actively engaged in research work with Union Carbide for the past 30 years. His research contributions have covered a wide range of activities in the fields of metallurgy, industrial gases and atomic energy.

An accomplished linguist, Dr. Kinzel has lectured to distinguished audiences in many countries abroad, including France, Italy, Germany, Austria and Sweden. In this country, he has given many honorary lectures before various technical societies.

He is a member of the AMERICAN WELDING SOCIETY.

Koopman Appointed by Welding Research Council

Kenneth H. Koopman has accepted the position of assistant director of the Welding Research Council of the Engineering Foundation as of March 1, 1958. He will also act as executive secretary of the Pressure Vessel Research Committee.

Mr. Koopman graduated from Rensselaer Polytechnic Institute in 1938 with the degree of Bachelor of Metallurgical Engineering. He then enrolled in the Loop Training Course of the Bethlehem Steel Corp. and, after completing it, was appointed a metallurgical assistant in the Blast Furnace Department at their Lackawanna, N. Y. plant. In 1940 Mr. Koopman joined the Union Carbide Corp. as a research metallurgist at their Niagara Falls Metals Research Laboratory and later in 1947 was transferred to their Linde Development Laboratory at Newark, N. J. He worked on the oxyacetylene, pressure, inert-gas tungsten-arc and metal-arc, and submerged-arc welding processes as well as on welding rod and flux development, materials application and conducting training courses for sales and engineering personnel.

In 1955 Mr. Koopman began working at the Knolls Atomic Power Laboratory of the General Electric Co. as supervisor of the Welding Metallurgy & Development Laboratory. At the Knolls, a varied experience was obtained on many types of welding and brazing applications along with material applications for nuclear power plants based on both the sodium cooled and pressurized water type reactors. During this time, he enrolled in the RPI Evening Graduate School. He obtained a master's degree in Metallurgical Engineering in January 1958.

Mr. Koopman holds a professional engineer's license in New York State and has been active in the AMERICAN WELDING SOCIETY since 1940. He served as secretary, vice-chairman and became chairman of the Niagara Frontier Section in 1946. He also served as treasurer, vice-chairman and became chairman of the New Jersey Section in 1954. Mr. Koopman has served on the National Program Committee of the AMERICAN WELDING SOCIETY. He is

Kenneth H. Koopman

also a member of the American Society for Metals. (The Junior Chamber of Commerce of Kenmore, New York was of great interest to him also. Mr. Koopman served as chairman of the Membership Committee for 2 years and helped to conduct vocational guidance clinics for the local high school in an effort to explain the highlights of the various engineering courses to prospective college engineering students. He also taught metallurgy courses for Cornell University extension school evening programs conducted in Buffalo, New York at about this same time of 1945.)

Several papers have been presented by Mr. Koopman at annual meetings of the AMERICAN WELDING SOCIETY and local meetings of the AMERICAN WELDING SOCIETY and American Society for Metals. He has been an author or co-author of 14 published papers.

Willecke to Head Research Group

N. C. Miller, president of Miller Electric Manufacturing Co., Inc., Appleton, Wis., announced the establishment of a complete research department and appointed G. K. Willecke as director of research to head the laboratory facility effective Feb. 4, 1958.

Mr. Willecke, formerly Assistant Professor of Physics at Lawrence College, joined the Miller firm as a consultant in 1947, and assumed full-time duties as physicist in the engineering department of the firm in 1950.

In his new position of director of research, Mr. Willecke will guide the long-range technical investigations and development of the welder firm. The

New LW-3

Only 14 ozs.

HI-AMP®

Presents America's Newest, Lightweight,

Designed with **HI-AMP'S** channel construction which insures rugged tong members, made from Kaiser Forged Aluminum for high tensile strength with replaceable jaws of tough **LENCO-LOY**.

High heat resisting glass fibre insulation that withstands rough treatment giving long service life. Insulation does not absorb moisture and insulates from heat as well as electrically. Insulating parts are interchangeable with **HI-AMP'S** popular Model F-3 heavy duty copper alloy holder.

Welding Cable connection uses two socket set screws with clamping plate to insure uniform pressure throughout length of welding cable contacting the holder.

Low Trigger design gives better balance for manual arc welding, reducing operator fatigue to a minimum.

Rated in top preference position by experienced welders who demand light weight, cool operation and long service life.

Sold through Welding Supply Dealers throughout the World.

Most Practical Aluminum Holder.

Light
Cool
Efficient
Economical

LENCO, Inc. JACKSON, MO.

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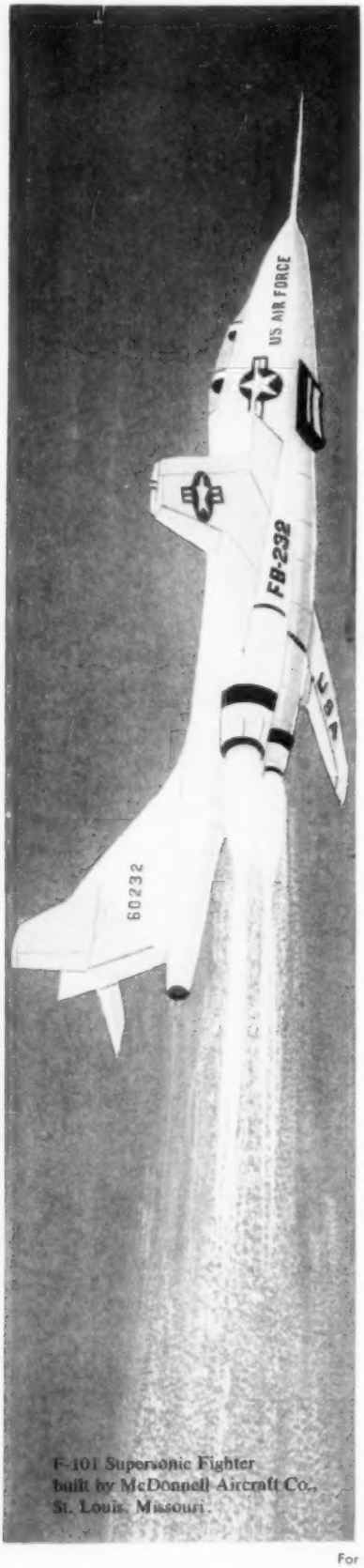


F-101 Supersonic Fighter built by McDonnell Aircraft Co., St. Louis, Missouri.

Aluminum dip brazing solves fabrication problem for fighter oil-cooling unit

The plate-type lube oil cooler of the F-101 supersonic fighter must cool the lifeblood of its engine dependably and efficiently in rarified atmospheres. Its design, consisting of a complex perforated grid enclosed in a crimped sheet envelope, demands strength to withstand 400 psi internal oil pressure. *Thousands of tiny grid surfaces had to be joined firmly to the plate envelope with the strength of a single unit.*

A joining problem such as this could only be solved by the aluminum dip-brazing technique. In this instance, Alcoa No. 6061 alloy was joined with Alcoa No. 22 brazing sheet by dipping in molten flux. Result, an all-aluminum unit of high corrosion resistance with strong and uniformly smooth joints.

Aluminum brazing offers many design approaches and advantages worth considering in the planning stage. Complicated assemblies with inaccessible joints can be made as a single unit which is smaller, lighter, more efficient *and* lower in cost. Close tolerances in small parts are obtainable—joints may be built up to desired strength.

Get in touch with Alcoa *before* you plan. We'll supply the information you need for welding, brazing or soldering aluminum. Contact one of the Alcoa distributors listed at the right or send for free information books and films on joining aluminum. Write to Aluminum Company of America, 1741-D Alcoa Building, Pittsburgh 19, Pennsylvania.

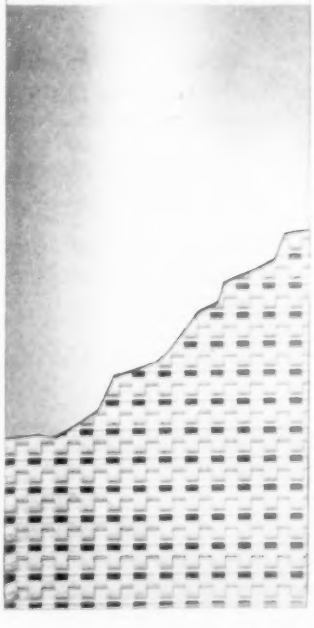
Your Guide to the Best in Aluminum Value

ALCOA ALUMINUM WELDING PRODUCTS
ALUMINUM COMPANY OF AMERICA

"ALCOA THEATRE"
Exciting Adventure, Alternate Monday Evenings

Plate-type aircraft lube oil cooler made by Clifford Manufacturing Co., Waltham, Mass., a division of Standard Thomson Corporation. Vertical plates and V-shape dividers or fins provide a heat transfer service of 32½ sq. ft. Oil is cooled by passage of air through these plates.

Cutaway of plate and interior grid through which oil flows.



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Want technical help in welding, brazing or soldering aluminum? Contact your Alcoa sales office, listed under "Aluminum" in the Yellow Pages of your phone book.

For immediate delivery of Alcoa welding products, call your Alcoa outlet listed below. He carries a complete range of alloys and sizes.

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Hinkle Supply Co.

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Pacific Metals Company, Ltd.
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COLORADO
Denver
Metal Goods Corp.

CONNECTICUT
Windsor
Whitehead Metal Products Co., Inc.

FLORIDA
Jacksonville
The J. M. Tull Metal & Supply Co., Inc.
Miami
The J. M. Tull Metal & Supply Co., Inc.
Tampa
The J. M. Tull Metal & Supply Co., Inc.

GEORGIA
Atlanta
The J. M. Tull Metal & Supply Co., Inc.
Southern Oxygen Co.

ILLINOIS
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Machinery & Welder Corp.
Steel Sales Corp.
Moline
Machinery & Welder Corp.

KENTUCKY
Louisville
Williams and Co., Inc.

LOUISIANA
New Orleans
Metal Goods Corp.

MARYLAND
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Southern Oxygen Co.
Whitehead Metal Products Co., Inc.
Bladensburg
Southern Oxygen Co.
Salisbury
Southern Oxygen Co.

MASSACHUSETTS
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Whitehead Metal Products Co., Inc.

MICHIGAN
Detroit
Steel Sales Corp.

MISSOURI
Kansas City
Metal Goods Corp.
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Metal Goods Corp.

NEW HAMPSHIRE
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Edgcomb Steel of New England, Inc.

NEW JERSEY
Harrison
Whitehead Metal Products Co., Inc.
Merchantville
Southern Oxygen Co.
Vineland
Southern Oxygen Co.

NEW YORK
Buffalo
Whitehead Metal Products Co., Inc.
New York
Southern Oxygen Co.
Whitehead Metal Products Co., Inc.
Syracuse
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Greensboro
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Southern Oxygen Co.

OHIO
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Williams and Co., Inc.
Cleveland
Nottingham Steel & Aluminum Co.
Williams and Co., Inc.
Columbus
Williams and Co., Inc.
Toledo
Williams and Co., Inc.

OKLAHOMA
Tulsa
Metal Goods Corp.

OREGON
Portland
Pacific Metal Co.
J. E. Haseltine & Co.

PENNSYLVANIA
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Edgcomb Steel Co.
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TENNESSEE
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San Antonio
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UTAH
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VIRGINIA
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Lynchburg
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Norfolk
Southern Oxygen Co.
Richmond
Southern Oxygen Co.
Roanoke
Southern Oxygen Co.

WASHINGTON
Seattle
Pacific Metal Co.
J. E. Haseltine & Co.
Spokane
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WEST VIRGINIA
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WISCONSIN
Milwaukee
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Steel Sales Corp.

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G. K. Willecke

Clifford D. McGuinn

efforts of the laboratory will be concentrated on several fundamental problems involving the arc-welding process and a systematic development of projects leading to future products.

Mr. Willecke has written a number of technical papers on welding and is on an authorizing committee for the new revised AWS handbook.

Mr. Willecke is a member of the AMERICAN WELDING SOCIETY.

Galton Made Sales Manager

Paul Galton has been appointed manager of sales for Worthington Corp.'s Plainfield, N. J. Division. He will be responsible for the sale of all products manufactured at Plainfield, including construction equipment, industrial mixers and positioning equipment.

Mr. Galton graduated from City College of New York as a mechanical engineer in 1941. He was sales manager for the Central Transformer Corp. before joining Worthington in 1955 as manager of Positioning Equipment Sales.

Mr. Galton replaces Paul J. Foley who has been appointed general manager resale for Worthington Corp.

Mr. Galton is a member of the AMERICAN WELDING SOCIETY

McGuinn and Moore Promoted by NCG

Appointment of Clifford D. McGuinn as vice-president in charge of field operations and Glenn Moore as controller of the NCG Division of National Cylinder Gas Co., Chicago, was announced by J. L. Adank, division president.

Mr. McGuinn will be in charge of regional and district sales and distribution of industrial and medical gases, welding and cutting equipment and medical equipment. He has been with the company since 1932. Following district sales positions in North Bergen, N. J., Buffalo, N. Y. and Chicago, he became assistant sales manager, northern division, in 1949 and sales manager, northern division, in June 1955. He is a member of the AMERICAN WELDING SOCIETY, International Acetylene Association and Compressed Gas Association.

Metallurgist Cited in India

Dr. B. R. Nijhawan, director, National Metallurgical Laboratory, Jamshedpur, India, has been given the award of "Padma Shri" by the president of the Union Republic of India on Republic Day, Jan. 26, 1958, in recognition of his exceptionally distinguished services in the fields of science in India.

BOUND VOLUMES OF 1957 JOURNAL NOW AVAILABLE

Bound Volumes of THE WELDING JOURNAL for the year 1957 are available in black imitation leather covers, together with a comprehensive subject and authors' index. Price $15, including postage.

This volume, comprising a total of 1260 pages in the JOURNAL and an additional 552 pages in the *Welding Research Supplement*, represents a veritable encyclopedia of information in the Welding field. Copies may be ordered through the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

Fast Process Cuts Repoint Time On Worn Dipper Teeth

The revolutionary Arcair process for metal removal has proved highly effective on dipper tooth preparation for repointing and other maintenance on heavy earth-moving machinery.

FAST, LOW-COST REMOVAL

The job shown above is a typical application. The Arcair Model H-3 Torch was clocked repeatedly at two minutes per tooth for removing stainless welds on worn repoints. About 1/2 of a 1/4" Arcair Copperclad electrode was consumed, at a total cost of 3 cents.

Similar tests with comparable results have been made on a variety of earth-moving equipment—dozer blades, buckets, pads, sprockets, idlers, rollers, tractor grousers, cast iron housings, crusher jaws, gyrator cones and concaves, crusher rolls, etc.

PROCESS DETAILS

The Arcair Torch uses ordinary compressed air at 80-100 psi and current from regular welding equipment with Arcair Copperclad electrodes. The electric arc causes the metal to melt, and an air jet paralleling the electrode blasts the molten metal aside.

The process uses D.C. on most metals, and is particularly effective on stainless steel, manganese steel, hard-surfacing alloys, cast iron and copper alloys. Cast iron and copper alloys, however, should be worked with A.C. current.

Because it does not depend on oxidation, Arcair cuts stainless and manganese as easily as mild steel. The Arcair process introduces less heat than any of the welding processes so that the physical properties of such materials as manganese steel are fully preserved.

INFORMATION AVAILABLE

For complete information or practical demonstration, contact your local welding supply distributor or write Arcair today.

Arcair COMPANY

431 S. Mt. Pleasant St., Lancaster, Ohio

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Poe and Townsend Promoted by Tweco

At the annual meeting held in Wichita, Kan., in January, Tweco Products, Inc. elected two new officers to the company. They are Roy W. Poe, vice-president, and James L. Townsend, secretary.

James L. Townsend

Mr. Poe has been with Tweco for 11 years. He will continue to serve as director of sales.

Mr. Townsend, a business administration graduate of the University of California, came with Tweco on completion of his college work in 1956. As secretary of the company, he will continue in an administrative capacity.

Roy W. Poe

The Messrs. Poe and Townsend are members of the AMERICAN WELDING SOCIETY.

Pike and Chumbley Appointed

Appointment of Thomas H. Pike, Jr. and John E. Chumbley as division vice-presidents and F. E. MacDonald as controller was announced in Louisville, Ky. by Tube Turns, a division of National Cylinder Gas Co., Chicago.

Mr. Pike will be in charge of planning and Mr. Chumbley will be in charge of general sales operations for the division.

Mr. Pike, who joined Tube Turns as west coast district manager at Los Angeles in 1940, became assistant sales manager at the main office in Louisville in 1945, was promoted to assistant general sales manager in 1953 and to merchandising manager in 1955.

Mr. Chumbley, with the firm since 1937, became manager of flange sales in 1940, forging division sales manager in 1945 and assistant general sales manager in 1953.

Mr. MacDonald joined Tube Turns in 1937 and became assistant controller in 1945. He is also assistant secretary and assistant treasurer of National Cylinder Gas Co.

Wade Named by Linde

Appointment of Sidney Wade as manager, distributor products, for Linde Co., Division of Union Carbide Corp., has been announced by W. M. Haile, Linde president. The new assignment centralizes responsibility for marketing activities and product sales through Linde's nation-wide organization of distributors and jobbers.

Mr. Wade brings into operation a personal background of more than 35 years' active experience in the welding and cutting industry. He began his business career with Union Carbide's Oxweld Acetylene Co. in 1921, after receiving his A.B. in Liberal Arts from the University of Illinois. He joined Linde in 1929, when the Oxweld Acetylene Co. was merged with the Linde Co.

Sidney Wade

With establishment of Linde's Gas Apparatus Department in 1956, Mr. Wade was named manager of the new department, assuming full responsibility for all phases of Linde's gas apparatus business. In his new assignment, Mr. Wade will continue in this capacity, with added responsibility for marketing activities on behalf of all Linde products.

Mr. Wade is a member of the AMERICAN WELDING SOCIETY.

Better Welding...

these manufacturers know how...
by AUTOMATIC arc control.

TENNESSEE EASTMAN COMPANY
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Some dealer territories available for qualified welder sales organizations. Write for information.

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OBITUARY

Ernest Victor David

On Tuesday morning, Feb. 11, 1958, Ernest Victor David was stricken with a fatal heart attack at his home in Santa Monica, Calif. He was 65.

E. V. David was born in the United States but studied mechanical engineering at the Winterthur Institute of Technology, Winterthur, Switzerland, where he graduated in 1912. Returning to the United States, he was employed by Newport News Shipbuilding and Drydock Co., Newport News, Va. until 1915. He then spent two years as inspector for U. S. Navy at Bethlehem Steel Corp., Ship Division, Quincy, Mass. Entering the U. S. Navy in 1917 as ensign, he served on the U. S. Flagship "Pennsylvania" throughout the World War, attaining the rank of senior lieutenant. He resigned in 1919 and accepted a position as marine engine designer at Federal Shipbuilding Co., Kearny, N.J. He left in 1920 to go with International General Electric Co. in Buenos Aires, Argentina. Returning to the United States in 1922, he served as an inspector for Hartford Steam Boiler Inspection and Insurance Co., New Orleans office until 1924. He resigned to take a position with U. S. Shipping Board, New York, as inspector, which he held until 1927. He then became connected with N. Y. Steam Corp. as assistant to the chief engineer. In 1929 he went with Air Reduction Sales Co., with which concern he held the position of assistant manager, Applied Engineering Department. He held various positions in the Industrial Relations Department just prior to retirement a few years ago. He was a member of the AMERICAN WELDING SOCIETY, International Acetylene Association and American Society of Mechanical Engineers.

Ernest Victor David

PLAN TO ATTEND

AWS ANNUAL SPRING MEETING

APRIL 14-18
HOTEL STATLER
ST. LOUIS, MO.

EMPLOYMENT SERVICE BULLETIN

Services Available

A-702. Engineer educated in Europe in mechanical, aeronautical, welding and metallurgical engineering would accept responsible managerial or supervisory position. Degree approximately equivalent to Ph.D. Over twenty years experience in research, development, organization, design, production, failure investigation and trouble shooting. Familiar especially with aluminum, ferrous and titanium alloys, corrosion and ultrasonics. East Coast preferred.

SEE AMAZING DEMONSTRATIONS AT THE WELDING SHOW, April 15-17 in St. Louis

. . . Or do-it-yourself in our booth No. 717. Big labor and time savings with no loss of efficiency are within your grasp with this new idea in fasteners . . . Circle Clamps. Write us now for complete details, including sizes of free production samples desired.

Circle Clamp Corporation
39 BROADWAY • NEW YORK, N.Y.

Circle No. 33 on Reader Information Card

METALLURGIST FOR WELDING RESEARCH

We are seeking a college graduate with 5-10 years' experience in welding research or development to participate in an expanded research program. Experience with heat resistant alloys helpful but not required. Permanent position with opportunities for personal advancement. Replies confidential.

Send resume to
George R. Pease
The International Nickel Co., Inc.
Research Laboratory
Bayonne, New Jersey

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Page 457

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On Stage at the A. W. S. welding show

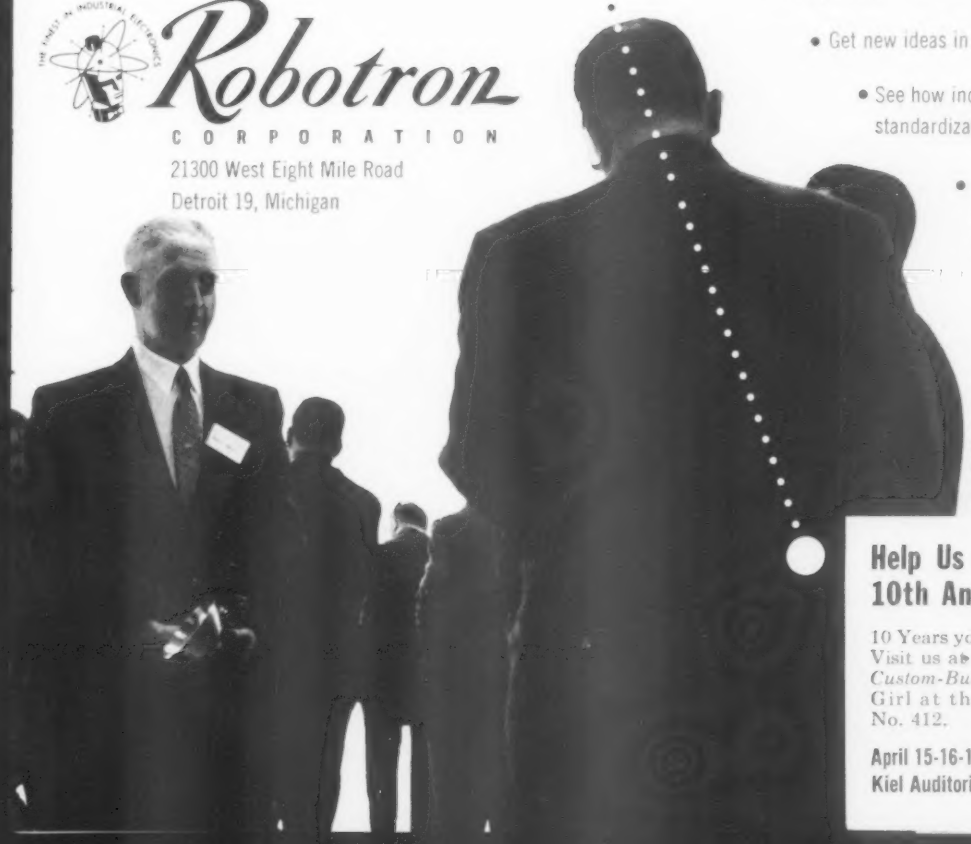
NEW TRENDS in RESISTANCE WELDING CONTROLS

featuring

The cost saving story of CUSTOMER SPECIFICATIONS

- See new specifications—today's guideposts for tomorrow's developments in industrial electronics.
- Get new ideas in resistance welding controls.
- See how individual customer specifications pioneer standardization—eliminate control variables.
- See industrial units designed and built to exact specifications for leading manufacturers

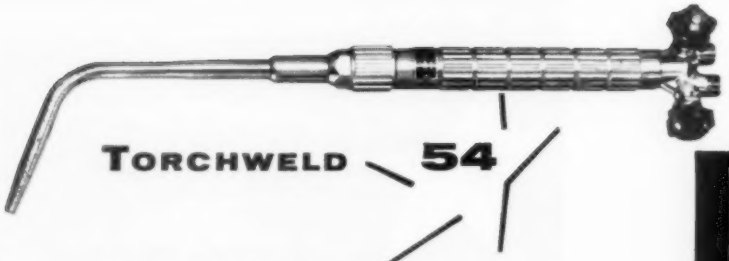
Robotron
CORPORATION
21300 West Eight Mile Road
Detroit 19, Michigan



Help Us Celebrate Our 10th Anniversary!

10 Years young and still growing! Visit us at the show. Meet *Miss Custom-Built*, the Specifications Girl at the Robotron Booth, No. 412.

April 15-16-17, 1958
Kiel Auditorium, St. Louis, Mo.

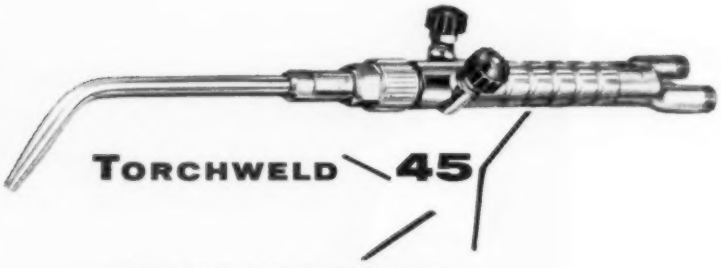


TORCHWELD 54

THE WIDE-RANGE, ALL-PURPOSE WELDING TORCH

This is the torch *par excellence* for all types of work, from 28 gauge sheets to 1" slabs or more. Has easy-adjustment non-seizing valve mechanism for precise control of gas pressure and flow. Mixer blends gas perfectly, delivers to tip without restriction. Both swaged and drilled tips are available to provide required flame characteristics.

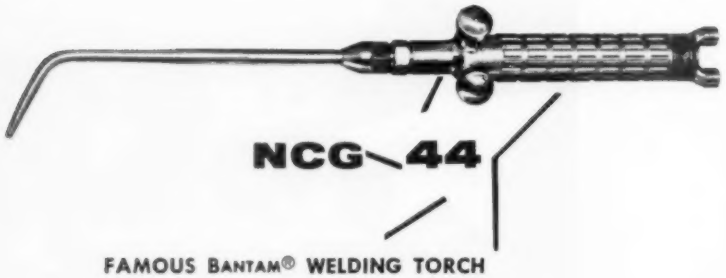
Rugged, tough stainless steel tubes . . . silver-brazed at head and base. Lightweight, strong brass handle, grooved to give sure grip and control. Mixer has buna seating rings for leakproof hand-tightening. No metal-to-metal contacts. No scratching or scoring. No costly reseating of torchhead.



TORCHWELD 45

THE LIGHT AND MEDIUM DUTY WELDING TORCH

For automotive welding, pipe welding, sheet metal fabrication, steam-fitting, etc. Aluminum handle, lightweight but rugged. Valve wheels placed conveniently at front end, under the thumb. Mixer delivers perfectly mixed gases. Mixer has buna seating rings for leakproof hand-tightening.



NCG 44

FAMOUS BANTAM® WELDING TORCH

Ideal for welding aluminum, alloys, aircraft tubing, steel from 28 gauge to ⅛" thick. Lightweight, easy to handle, compact for use in tight quarters.

Valve wheels placed conveniently at front end, under operator's thumb. Special nickel alloy tubes, silver-brazed at head and body. Non-seizing, non-scoring stainless steel valve stems. Mixer designed for perfect gas mixing.

TORCHWELD®

The All-Star Line of Welding and Cutting Equipment

In this outstanding line of regulators, torches, tips and accessories you will find features galore. Operating features that boost production, handling features your operators go for: cost-cutting features, durability and dependability. All backed by a great manufacturing and engineering organization and a nation-wide network of dealers offering prompt service in every respect. Ask your nearest authorized NCG dealer or NCG office for a demonstration. Or write for a complete catalog.

NCG®

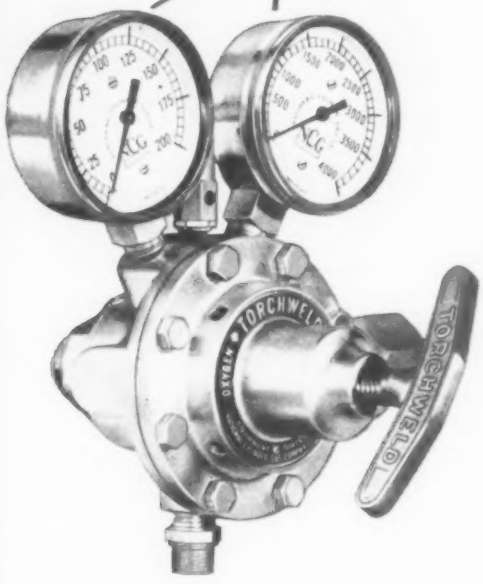
NATIONAL CYLINDER GAS COMPANY

840 NORTH MICHIGAN AVENUE, CHICAGO 11, ILLINOIS

Branches and dealers from coast to coast

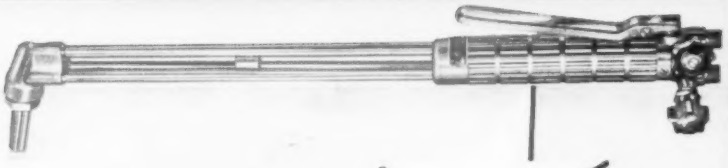
For more details, circle No. 35 on Reader Information Card

TORCHWELD 6500 Regulators



TWO STAGE PERFORMANCE AT SINGLE STAGE COST

The best features of both types of regulators—the *dis*advantages of neither . . . that's what you get in the 6500 Series Regulators. That's because of the patented pressure compensating chamber. It maintains desired set pressure *throughout the usable cylinder range!* Yes, here's simple construction, low initial cost, and the precise control of pressures and volumes found elsewhere only in the more expensive two stage regulators.



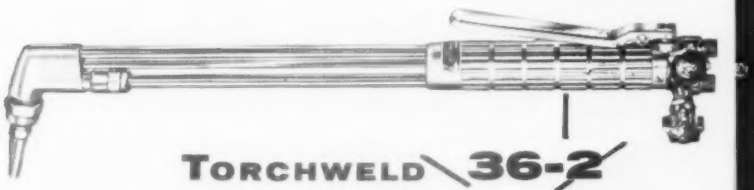
TORCHWELD 75-1

THE OUTSTANDING CUTTING TORCH

This is the ideal performer for operations of any size or any kind, from small shop to huge mill. Cuts sections up to 16 inches thick.

Pressure-forged, rugged brass valve body; non-seizing stainless steel needle valve stems. Non-warping forged bronze or abuse-resistant nickel alloy heads. Nickel-alloy tubes, set in self-reinforcing triangular formation. Silver-brazed into handle and head. Precision-swaged tip orifices for perfect gas flow and clean, sharp kerfs.

Long control lever, equipped with exclusive *packless* valve. Gives positive smooth control even at lowest rates of flow. Pre-heat gases are blended in tip.

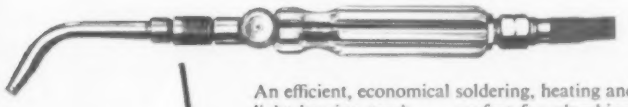


TORCHWELD 36-2

SPECIAL CUTTING TORCH FOR WIDE RANGE OF GASES

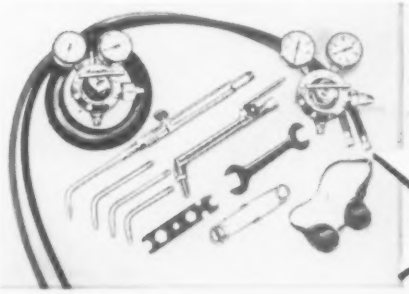
A medium pressure pre-mix type cutting torch designed for use with propane, butane, natural gas and city gas as well as acetylene. A fast economical cutter, its capacity ranges up to 16 inch sections.

Top or bottom lever, 75° or 90° forged bronze head. New packless type valve, far outlasts conventional types. Better control and smoother flow of cutting oxygen. Universal type silicon-bronze mixer. Precisely blends preheat gases through entire range of tip sizes. Nickel-alloy tubes, silver-brazed to head and body. Rugged, heavy-duty brass handle, grooved for sure grip and control.



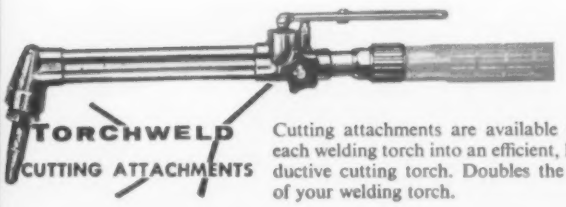
SOD-R-BRAZE® ACETYLENE-AIR TORCH

An efficient, economical soldering, heating and light brazing torch . . . perfect for plumbing, refrigeration, automotive, electrical, maintenance and repair work. Three-way thumb control. Operator turns on and off, adjusts flame and sets pilot light—all with a flip of the thumb. Tips have individual mixers. 6 different sizes for a wide range of work.



TORCHWELD READY-TO-USE OUTFITS

A wide range of ready-to-use complete outfits for every welding and cutting need in every type of shop or plant. All needed accessories are included. Outfits cost less than the total price of components when bought separately.



TORCHWELD CUTTING ATTACHMENTS

Cutting attachments are available to convert each welding torch into an efficient, highly productive cutting torch. Doubles the usefulness of your welding torch.

NEW LITERATURE

Electrode Selector Guide

A new 40-page pocket size "electrode selector guide," No. AR 20-3, published by Alloy Rods Co., York, Pa. reportedly contains a complete listing of ASTM steel classifications and recommended electrodes for welding each grade; also AISI stainless-steel type numbers, chemical analysis and recommended electrodes. A complete table of "Arcaloy" stainless-steel electrodes, their chemical analyses, physical properties, and a brief description of the use of each type is also included. For welding low-alloy steel, a table of "Atom Arc" iron-powder low-hydrogen electrodes, their chemical analyses, physical properties, a description of each type and complete current-range table is included.

For your free copy, circle No. 36 on Reader Information Card.

Welding Directory

The 1958-59 edition of the Welding Directory, a reference guide to welding, cutting, brazing and auxiliary equipment and supplies has just been published by the Industrial Publishing Corp., Cleveland, Ohio.

Compiled and edited by the editors of Industry & Welding and Welding Illustrated magazines, the 680-page directory lists more than 350 products, 1700 different trade names and more than 2000 welding distributors.

It is divided into five sections, namely: product directory, trade names index, manufacturers' catalog section, reference manual and a section which describes "where to buy it locally."

Copies of the Welding Directory may be ordered at $6.50 each from the Industrial Publishing Corp., 812 Huron Rd., Cleveland 15, Ohio.

Machine Maintenance Chart

A. O. Smith Corp., Milwaukee 1, Wis., has developed a maintenance chart covering protective maintenance for a-c and d-c welding machines. This chart is reportedly applicable to all welding machines, regardless of manufacture.

The chart, available free of charge, is large (15 x 23 in.), printed on heavy enamel stock in color, with easy-to-read type for mounting on shop bulletin boards or close to wherever welding is being done.

Material furnished on the 15- x 23-in. chart includes "trouble shooting" tables on both a-c and d-c models and recommended cable and fuse sizes. Trouble

shooting charts include trouble, cause and remedy columns.

For your free copy, circle No. 37 on Reader Information Card.

Alloy News

Volume 3, No. 1 of *Colmonoy Alloy News* is now available from Wall Colmonoy Corp., 19345 John R. St., Detroit 3, Mich. This January-February issue contains articles discussing the hard surfacing of mild steel chipper inserts and of concrete pipe forming shoes. Other articles are included on brazing and spray welding.

For your free copy, circle No. 38 on Reader Information Card.

Oxygen Cutting

A new 16-page catalog covering the features of the new No. 56 Oxygraph flame-cutting machine has just been made available by Air Reduction Sales Co., a Division of Air Reduction Co., Inc., 150 E. 42nd St., New York 17, N.Y.

Entitled, "56 Oxygraph Flame Cutting Machine," Catalog 804B deals with the design and performance features of this new multiple-torch model. Sections of the catalog discuss the gas-distribution system and the various accessories which include the electronic tracer, the heavy-duty magnetic tracer, and the manual and spindle tracers. Manual torch holders, torches and machine cutting tips are also discussed with data for their use.

For your free copy, circle No. 39 on Reader Information Card.

Ultrasonic Testing

Applications of ultrasonic inspection methods and equipment to quality control, production testing and preventive maintenance are described in the booklet, "Inside Information on Ultrasonic Testing," published by Sperry Products, Inc., of Danbury, Conn.

The booklet reportedly explains how the technique reduces or eliminates waste by preventing the machining of faulty materials, insuring product quality and maintaining machinery in safe-operating condition.

The illustrated booklet presents brief descriptions of the Sperry Products Reflectoscopes and accessories, and outlines how any company may utilize ultrasonic inspection by employing commercial testing services or by leasing test equipment.

For your free copy, circle No. 40 on Reader Information Card.

Resistance Welding of Mild Steel

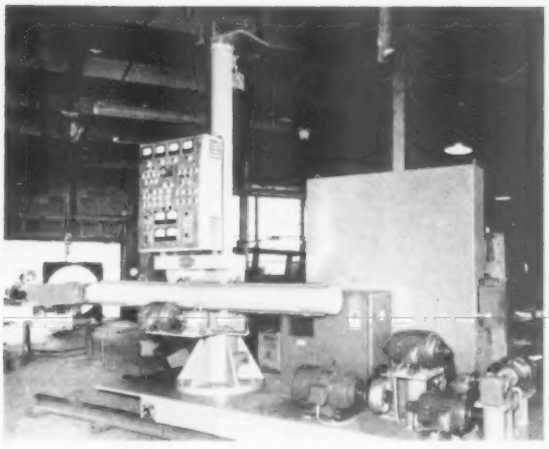
Sciaky Bros., Inc., 4915 W. 67th St., Chicago, Ill., announce the availability of a fifty-page engineering report devoted to tentative design standards for resistance formed welds in mild steel. These technical data were compiled recently by a leading manufacturer of farm implements and machinery.

Line drawings are used extensively to illustrate various piece-part combinations, e.g., solid bar to round stock, tube to tube, round on end to flat stock, etc. Total secondary amp, current densities, time in seconds, area fused in square inches and other information are contained on numerable and comprehensive graphs. Tabulated data and formulae are also included.

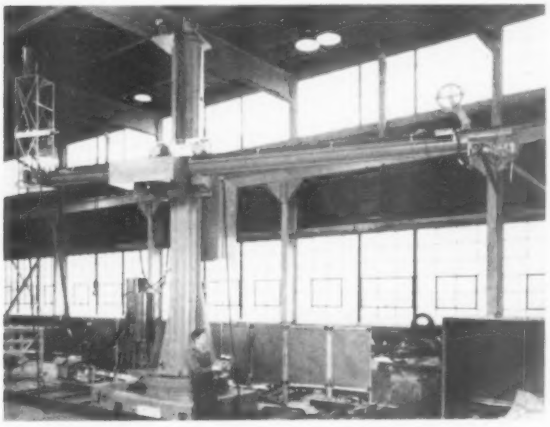
For your free copy, circle No. 41 on Reader Information Card.

Electrode Holder Catalog

Catalog No. 11 has just been issued by Tweco Products, Inc., Boston at



Complete welding control of two heads either simultaneously or independently (arc start & stop, wire inch up & down, current raise & lower, flux feed, etc.). Four tachometers and welder meters in pendant. Complete control of ram machine movements with four speed ranges for carriage travel (.01"–.20", .20"–4", 5"-100" and 300" per minute rapid traverse). Electronically variable speed ram drive provides 5 to 100 imp travel speed. Motorized cross adjustment of both heads 0° to 48° arc to arc. Motorized vertical adjustment 6' using double chain and counterweight. Full 360° rotation within base.



Motorized vertical adjustment of 15' (3' to 18'). Variable speed ram travel of 20'. Rotation on carriage of 360°. Automatic flux feed thru ram. Wire feed from rear or forward end of ram. Head will enter 24" diameter cylinder. Power supply and flux recovery units mounted on rotating base plate. Variable speed travel of entire unit on any length of track. Operator may be seated at forward end of ram. All ram machine and welding controls in portable pendant.

Motorized vertical adjustment of 12'. Variable speed ram travel of 20'. Motorized rotation 360°. Special head mounting with separate motorized adjustment. Rapid traverse of ram travel 300 imp. Wire feed from rear of ram through insulated tube. All ram machine and welding controls in portable pendant.

Largest exclusive builders of RAM-TYPE MANIPULATORS

Many models and sizes.

Advanced design and features.

New electronic drive units.

Impressive appearance.

Precision parts and workmanship.

Unmatched performance.

Long life-minimum maintenance.

A superior machine at low cost.

Tested completely before shipment.

Operates easily and efficiently.

Rugged, welded construction.

Special controls available.

WRITE FOR NEW DESCRIPTIVE INFORMATION

C. B. HERRICK MFG. CORP.

2000 CENTER ST., CLEVELAND 13, OHIO

For more details, circle No. 42 on Reader Information Card

Mosley, Wichita, Kan. This new 12-page catalog includes Tweco's new line of electrode holders which feature "ball-point screw cable connections" designed to eliminate the major spot for overheating. Also itemized are cable connectors, terminals, jacket grippers, cable connection supports and cable lugs.

For your free copy, circle No. 43 on Reader Information Card.

Resistance Welding

A 4-page bulletin, *Weld It*, has just been issued by the Taylor-Winfield Corp., Warren, Ohio. Included in this recent release, No. 5711, is an article describing resistance-welding methods in joining Type 302, stainless-steel side-plate assemblies for flow meters at Fischer & Porter Co. Another article describes welding operations involved in the production of generator field coils at the Electric Auto-Lite plant.

For your free copy, circle No. 44 on Reader Information Card.

Electrode Directory

A new 12-page Weldirectory has been published by the Lincoln Electric Co. of Cleveland, Ohio.

To help select the best electrode for overhead, downhand, sheet metal or other work, the Weldirectory first describes the basic characteristics of each family of electrodes. This description includes deposition, arc action, amount of slag, bead appearance and general applications. Then the Weldirectory differentiates between individual electrodes within the family and gives physical properties, current ranges, sizes and welding procedures for each electrode.

The back of the Weldirectory is a wall chart containing frequently used information about Lincoln electrodes.

For your free copy, circle No. 45 on Reader Information Card.

Inert-Gas-Welding Catalog

A revised 24-page catalog on Heliwelding, Air Reduction's inert-gas-shielded tungsten-arc welding process, has been announced by Air Reduction Sales Co., a division of Air Reduction Co., Inc., 150 E. 42nd St., New York 17, N. Y.

New items listed in the revised catalog include the Model HMC-A "Heliweld" weld cycle control which has been designed to provide programmed control of all functions for "Heliwelding" using machine holder with d-c straight polarity; the Model H20-A manual "Heliweld" holder pack containing a 25-ft cable and hose assembly; the Model SH25-C "Aircospot Gun" for producing small circular welds (arc spot welding); the Model SHC-B "Aircospot" crater eliminator control; and types of tungsten electrodes with centerless ground finish.

For your free copy, circle No. 46 on Reader Information Card.

Welding Fitting Data

A new 16-page illustrated booklet published by the Tubular Products division of the Babcock & Wilcox Co., Beaver Falls, Pa., Booklet TB-417, presents information on the application of tubing, pipe and welding fittings. Included are application data, points to consider in selection of materials, analysis, physical, mechanical and creep-strength properties of various steels. The information can reportedly assist the buyer or engineer in determining the proper material to specify and also indicate the latest techniques in fabrication. Popular analyses, from carbon steel through stainless steel and titanium, are covered in this new booklet.

For your free copy, circle No. 47 on Reader Information Card.

Abrasive Wheel Catalog

A new catalog treatment has been given to the subject of abrasive mounted wheels by the Bay State Abrasive Products Co. of Westboro, Mass.

General information with regard to grinding action, wheel markings, grade, bond types, abrasive types, structure, grain size, spindles and treatments are discussed. Specification recommendations are also included.

The availability of mounted wheels has been set forth in chart form which reportedly gives all information on standard mounted wheels at a glance. A standard stock list and complete speed tables are also included in the catalog.

For your free copy, circle No. 48 on Reader Information Card.

X-Ray Microscope

A new 6-page Norelco folder titled "A High-Resolution PMR X-ray Microscope with Electron Microscope Conversion" is available from the Instruments Division, Philips Electronics, Inc., 750 S. Fulton Ave., Mount Vernon, N. Y.

The text was prepared by physicist Irwin I. Bessen and it gives complete scientific details on the new instrument—the first commercial X-ray microscope which determines the chemical composition of the specimen.

Wow—What a BUY!!
BIG 98
ALL PURPOSE COMBINATION WELDING AND CUTTING OUTFIT
PRICED $98.00
Never before at this LOW price!
Smith's new "Big 98" for $98
All-purpose welding cutting outfit
SMITH'S BIG 98

DOES MULTIPLE JOBS—welds, cuts, heats, brazes, solders . . . *offers an exceptional value unmatched in the welding industry today.* Cuts to 1"; welds to ¾". Additional tips increase cutting range to 4"; welding capacity to ¾"—also adapt torch to scarfing, gouging, etc. Assures clean, high-speed cuts with minimum gas consumption.

Here's what you get—torch body, 3 welding tips, cutting assembly, cutting tip, oxygen and acetylene regulators, goggles, lighter, and hose—all for only $98.00 (U.S.A.).

MANY FEATURES include . . . Slip-In Tips that tighten with fingertip pressure only . . . no wrench needed. Exclusive "Flo-Trol" diaphragm stops causes of backfires; eliminates seat burn-out; reduces downtime. Brand new bright-nickel finish.

SMITH'S

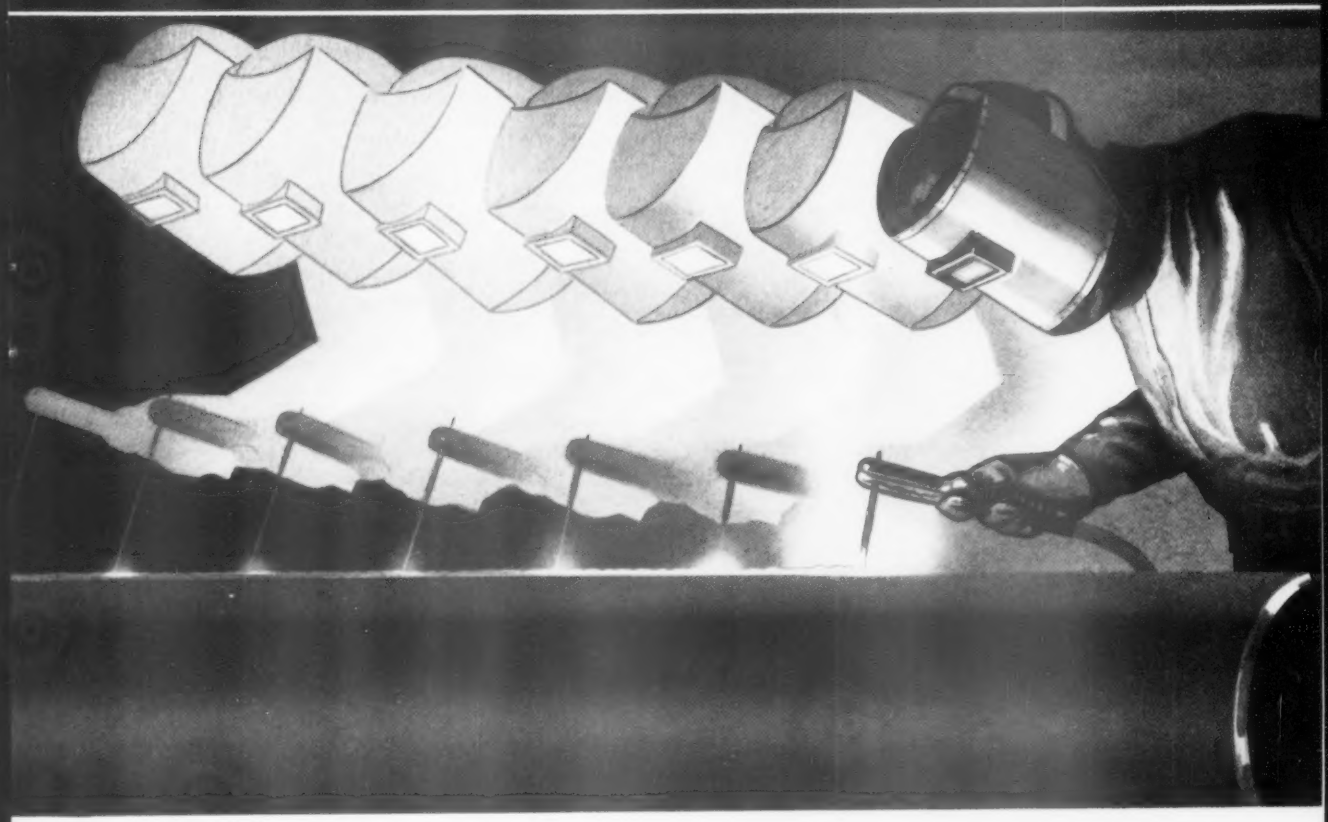
SMITH WELDING EQUIPMENT CORPORATION

Go great—go "Big 98" in '58

2637 FOURTH STREET S. E., MINNEAPOLIS 14, MINNESOTA

For more details, circle No. 49 on Reader Information Card

NEW MUREX® IRON POWDER "Hot Rod"



SPEEDEX TRIPLEX

another NEW product

matches deposit rates of automatic welding..

Manual welding speeds as much as 40% faster than competing electrodes—deposit rates up to 16 lbs. of weld metal an hour—have been obtained in actual tests with TRIPLEX, the new Murex iron powder electrode. Designed for high speed downhand welding with either drag or open arc technique, it produces X-ray quality welds with ultimate strengths of 62,000 to 66,000 psi and elongations of 30 to 33%.

SPEEDEX TRIPLEX offers all the usual advantages of iron powder electrodes. It has good arc characteristics and an easily removed slag. In addition it operates equally well on AC or DC and, in the ¼" diameter, at currents up to 450 amps. It is by far the fastest of the MUREX SPEEDEX line and is especially suited to the welding of large fabrications such as ship sections, freight cars, machine frames and pressure vessels.

Write for specific information on SPEEDEX TRIPLEX. Ask, too, for Folder IP-57 describing the entire SPEEDEX iron powder line.

METAL & THERMIT CORPORATION
Rahway, New Jersey

For more details, circle No. 50 on Reader Information Card

Information covers the construction of the new instrument as well as its application. Specific sections treat such subjects as components, nature of spectra, and absorption analysis and results obtained.

For your free copy, circle No. 51 on Reader Information Card.

Surfacing Bulletin

The importance of surfacing regarding "preventative maintenance" with respect to construction equipment is explained in a new, 2-color, 4-page brochure just published by Rankin Manufacturing Co., 616 So. Marengo, P. O. Box 631, Alhambra, Calif.

The brochure points out the "surface wear" problems and reportedly tells how Ranite helps obtain the very best hard-surfacing protection. A new Select-O-Graph Guide permits the user to choose the proper hard-surfacing rod for various wear conditions using Ranite's "job-graded, color-coded" welding electrodes.

A new method for keeping records of wear on all construction equipment is explained. This method affords a running check on parts of equipment that were hard surfaced and the estimated date when they will need hard surfacing again.

For your free copy, circle No. 52 on Reader Information Card.

Titanium

Papers presented at a symposium on physical metallurgy sponsored by the Metallurgical Advisory Committee on Titanium of the Army Ordnance Corps are contained in a volume just released to industry through the Office of Technical Services, U. S. Department of Commerce.

The symposium was held in September 1955 at the Army's Watertown Arsenal. Twenty-two metallurgical studies of titanium were read by technologists with the Army and its research contractors.

The papers cover such subjects as the effects of interstitial elements and grain structure on the properties of a number of different titanium alloys, and their thermal stability at high temperatures. Hydrogen contamination in the metals was given considerable attention.

The report, PB 131105 *Minutes of Physical Metallurgy Symposium*, Ordnance Corps, U. S. Army, September 1955, may be ordered from OTS, U. S. Department of Commerce, Washington 25. It contains 72 pages, price $2.

Resistance-Welding Bulletins

The Resistance Welder Manufacturers' Assn. has recently added two new bulletins to the list of technical literature available.

Bulletin No. 24 contains an informative article on "Metal Finish Seam Welding" and Bulletin No. 25, the latest in the series, deals with "Spot Welding 65-35 Brass on Single Phase Equipment with Slope Control."

Both publications are available at 15c each (please send stamps or coins with your order) from the Association's headquarters at 1900 Arch St., Philadelphia 3, Pa.

Refractory Metals

The September 1957 issue of "Fansteel Metallurgy" is available from Fansteel Metallurgical Corp., Metals & Fabrication Division, North Chicago, Ill. This 4-page brochure contains information on such refractory metals as tungsten, molybdenum, tantalum and columbium.

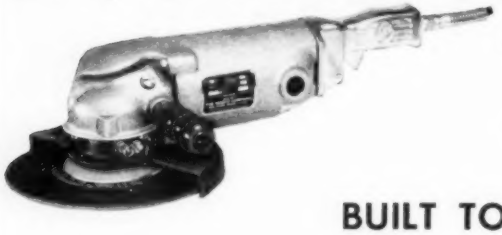
For your free copy, circle No. 53 on Reader Information Card.

ASTM's Gillett Memorial Lecture

The June 1957 Gillett Memorial Lecture of the American Society for Testing Materials, "A Perspective of Molybdenum-Base Alloys," by Alvin J. Herzig, president of Climax Molybdenum Co., is sponsored jointly by the American Society for Testing Materials and the Battelle Memorial Institute, commemorating Horace W. Gillett, first director of Battelle and subsequently its chief technical advisor. The lectures are always in the field of metallurgy which was the life work of Doctor Gillett. The topic, Molybdenum-Base Alloys, is particularly timely because of the tremendous need for metals that can withstand high temperatures and yet maintain physical strength.

FOR THOSE TOUGH JOBS CHOOSE THE

Nedco SANDBRUTE



A HEAVY DUTY
2 H. P.
9" GRINDER
AND
BUILT TO USE IT ALL

HAS THE
POWER (2 HP AT THE SPINDLE)
HIGH SPEED (6000 or 5300 RPM)
LIGHT WEIGHT (ONLY 13¼ LBS)

SEE & TRY THE NEDCO BEFORE YOU BUY

The Genuine NEDCO is Built only by

THE Nedco COMPANY 27 JONES ROAD, WALTHAM 54, MASS.

Pioneer Builders of Portable Electric Grinders SINCE 1926
WRITE FOR CIRCULAR ON COMPLETE LINE

For more details, circle No. 54 on Reader Information Card

Technical Welding Data:
USS "T-1" Constructional Alloy Steel

2. How to weld

USS "T-1" Steel can be welded by any of the following processes:

1. **Shielded metal arc (covered electrodes)**
2. **Submerged arc**
3. **Inert-gas-shielded arc**

The thermal cycle of these processes does not harm the unusual physical properties of this quenched and tempered constructional alloy steel. Other welding processes which subject the steel to prolonged heating, with a resultant slower cooling rate, should not be used with USS "T-1" Steel without first establishing the suitability of the process.

SHIELDED METAL-ARC WELDING. Low-hydrogen electrodes of the E-9015 and E-9016 to the E-12015 and E-12016 classifications should be used to weld USS "T-1" Steel. (Suitable low-hydrogen iron powder electrodes of the same strength range are now available.)

To develop 100% joint efficiency, even with reinforcements removed, electrodes of the E-120 class should be used. Lesser, but often adequate, efficiencies can be obtained with electrodes of lower classification.

If a weldment must be stress-relieved, Nickel-Molybdenum-Vanadium type electrodes must not be used because the heat of stress-relieving, while it does not affect the steel itself, does reduce the toughness of the weld metal.

When welding USS "T-1" Steel to other types of steel, use low-hydrogen electrodes of strengths suitable for the other steel. Remember that weld metals under these conditions develop greater yield and ultimate strengths because admixing of elements from the USS "T-1" Steel enriches their usual chemical compositions.

SUBMERGED-ARC WELDING. Since the currents used in this process are often higher than those used in hand welding, extra care should be taken when welding USS "T-1" Steel to prevent excessive heat input to the base metal. Use multipass welding wherever possible and keep the heat input per inch below that generally used with manual welding.

When you weld USS "T-1" Steel by the submerged-arc process, perform preliminary tests to determine the optimum speed, voltage, amperage, and other welding conditions for the various thicknesses involved before you start welding the finished work. Don't use semi-automatic submerged-arc welding, in which the welding speed is controlled manually, unless you can maintain good control of the speed and, hence, of the heat input.

INERT-GAS-SHIELDED ARC WELDING. Some USS "T-1" Steel weldments have been made by this process with satisfactory results. In these instances, when Nickel-Molybdenum-Vanadium electrodes were used, the weld metal deposited had properties very similar to those obtained with covered electrodes of the Nickel-Molybdenum type.

REMEMBER THIS: In what other alloy plate steel would you find the combination of properties that "T-1" Steel possesses? Here, in just one steel, you get very high yield strength (90,000 psi minimum), extraordinary toughness, great resistance to impact abrasion, and good high temperature strength. These let you reduce the size of highly stressed parts . . . save weight, reduce the amount of welding required, and cut your costs. USS "T-1" Steel is being used in bridges, excavating equipment, pressure vessels, towers . . . in equipment that must take heavy abuse in sub-freezing temperatures . . . in equipment that must withstand heavy stresses and impact abrasion at temperatures as high as 600° F.

WRITE FOR COMPLETE INFORMATION about the application and fabrication of USS "T-1" Steel, United States Steel, Room 5604, 525 William Penn Place, Pittsburgh 30, Pa.

United States Steel Corporation—Pittsburgh
Columbia-Geneva Steel—San Francisco
Tennessee Coal & Iron—Fairfield, Alabama
United States Steel Supply—Warehouse Distributors
United States Steel Export Company

USS United States Steel

USS and "T-1" are registered trademarks

For more details, circle No. 55 on Reader Information Card

Copies can be obtained from ASTM 1916 Race St. Philadelphia 3, Pa., at $1.50 each.

Automatic Arc Welding

Resistance Welder Corp., Bay City, Mich., has issued 2-page bulletin No. ARC 5803 which describes with illustrations various automatic arc-welding machines designed by the Michigan firm. Two units are for use with CO_2 gas in welding inner hub assemblies and compressor shell halves.

For your free copy, circle No. 56 on Reader Information Card.

Magnesium

Copies of the proceedings of the Magnesium Assn., are now available for general distribution from the association offices, 122 E. 42nd St., New York 17, N. Y. A charge of $5.00 a copy is made for this 160-page booklet which contains the 14 principal addresses and technical papers presented at the October meeting in New York.

Built around the meeting theme, "Magnesium in Perspective," this book is profusely illustrated. Titles of the papers appearing include the following: "Dip Brazing of Magnesium Possible, Practical and Efficient," and "Workable Method for Continuous Welding of Magnesium Proves Highly Efficient."

Saw Blade Chart

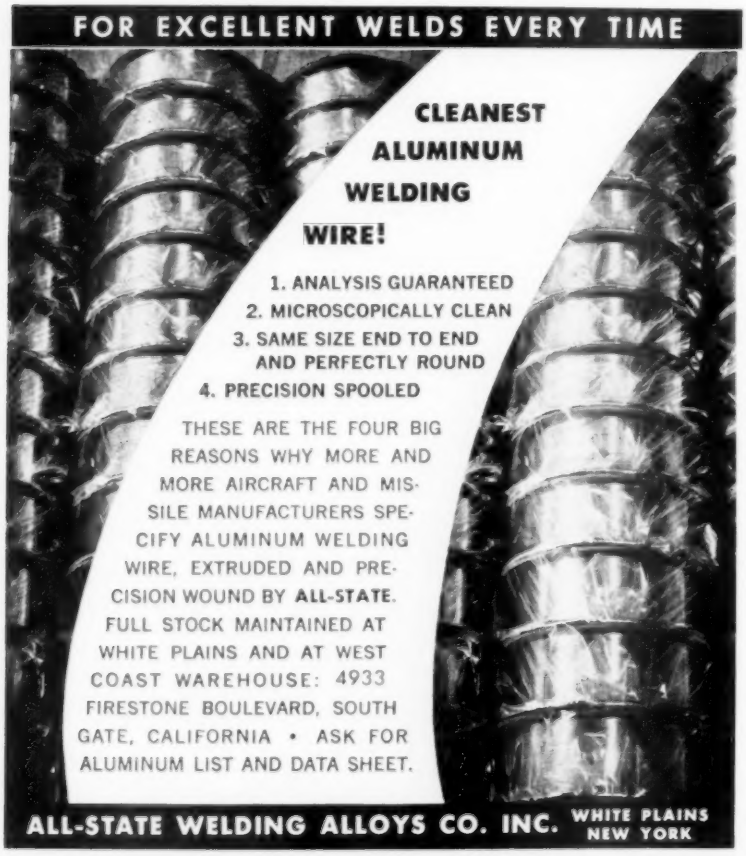
The DoAll Co., Des Plaines, Ill., announces a wall chart for shop use as an aid to the selection of the proper saw blade for specific sawing jobs. This chart lists the various sawing factors affecting cutting rate, tool life and finish. It shows the steps to proper blade selection and methods used to control these sawing factors for job requirements. It lists the recommended cutting rates for carbon steel and high-speed steel saw bands in relation to material work thickness as well as the saw pitch and lubricants to be used and the proper tool velocities for cutting 48 metals ranging from alloy steels to nickel base and titanium alloys.

For your free copy, circle No. 57 on Reader Information Card.

Soldering Aluminum

The Aluminium Development Assn., 33 Grosvenor St., London, W. 1, England, announces the availability of Bulletin No. 23, *Soldering Aluminum*. This 35-page booklet covers such areas as definitions, basic principles, description of available forms of solders, description of fluxes, and methods and equipment.

For your copy, write to the above source enclosing 18c.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REVIEWS
OF NEW BOOKS

Arc Welding

New Lessons in Arc Welding, second edition, 320 pages, illustrated with pictures and drawings, 6 by 9 in. Gold embossed, simulated leather cover. Price $1.00 postpaid in USA, $1.50 elsewhere. Published by the Lincoln Electric Co., Cleveland, Ohio.

The Second Edition of *New Lessons in Arc Welding* is a revision of this reference book on manual arc welding. The book has been rewritten and reorganized to make it easier to read and use as a text or a reference, and to include information on new procedures, machines and electrodes. Based on arc-welding courses taught at the Lincoln Arc Welding School and the experience of other arc-welding teachers throughout the nation, it is a practical text for teaching arc welding in vocational, trade and industrial courses. It also is a reference book for welders, supervisors and others using arc welding in industry.

The book is divided in seven separate sections with each section comprising several lessons. The first section deals with specific instructions on arc-welding techniques and related welding information necessary to the development of the techniques. The next five sections pertain to the proper use of welding machines and electrodes. A final section is principally devoted to reference material on metals, procedures, testing and weld symbols.

Resistance-Welding Manual

The Control and Resistance Welding (A Manual for the User), by Charles Paxton, application engineer, and William H. Smith, Detroit Sales Department, Weltronic Co., paper-bound book. Price $2.00. 205 pages. First edition. Published by Weltronic Co., Detroit 11, Mich.

This book is subdivided into four main sections, namely: selection of equipment, installation of equipment, general theory of operation and maintenance. The purpose of the manual is to acquaint individuals exposed to resistance-welding machinery and controls with standards, nomenclature, operation and maintenance of such equipment. According to the authors, its intent is to encourage research.

Numerous diagrams and tables are used to illustrate the various phenomena involved in resistance welding.

Data on Alloy Steels

Compilation of Chemical Compositions and Rupture Strengths of Super-Strength Alloys. ASTM Special Technical Publication No. 170-A. 6 pages, 8½ x 11 in., Self cover, $.75. American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

This compilation lists the name, nominal chemical composition, characteristic rupture strengths for rupture in 100 and 1000 hr, and patentee for approximately 150 domestic and 75 foreign alloys. The compilation includes the ferritic (martensitic) alloys and age-hardening stainless steels. It does not include the conventional austenitic stainless steels.

This compilation of data was originally prepared for a subcommittee of ASTM Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys to assist in writing specifications for high-temperature super-strength alloys. STP 170-A is a revision of STP 170 to which has been added data on ferritic (martensitic) super strength alloys.

Copper

ASTM Standards on Copper and Copper Alloys. September 1957 (B-5). 688 pages, 6 x 9 in., Paper cover: $6.25 (Cloth cover: $7.00). American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

A new edition of the special compilation of ASTM standards covering copper and copper alloys, cast and wrought, has recently been published. Thirty-four of the 128 standards included in the now obsolete December 1955 edition were revised in 1956 and 1957, and the revised standards are in the new edition. Also included for the first time are specifications for threadless copper pipe and for copper drainage tube.

Products covered include: basic coppers, nonferrous metals used in the manufacture of copper alloys, copper and copper alloy wrought products including electrical conductors, copper alloy ingots and castings, and copper and copper-alloy filler metal. Test methods for these materials accompany the specifications. A 16-page index appears at the back of the book.

Fatigue

1956 References on Fatigue. ASTM Special Technical Publication No. 9-H. 68 pages, 8½ x 11 in., duplicated, $3.00. American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

This is a list of about 370 references to articles published in 1956 dealing with fatigue of structures and materials. An abstract of each reference is included in all but a few cases. The material is so arranged that individual references can be cut apart for filing on cards according to any desired plan.

The list of references is a publication sponsored by ASTM Committee E-9 on Fatigue. A total of seven lists have now been published covering the years 1950 through 1956. The entire set of seven lists of references, STP Nos. 9-B through 9-H, may be purchased for $10.00.

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FOR FASTER, BETTER TUNGSTEN INERT GAS WELDING

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- Three torches in One . . . perfect welds from 3 to 350 Amps.

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For more details, circle No. 61 on Reader Information Card

ELECTRODE MANUFACTURER SEEKS PATENT ARRANGEMENT

Belgian electrode manufacturer — SOUDOMETAL, Anderlecht-Brussels wishes to negotiate the rights on U. S. patent No. 2,664,488 covering *special Deep Penetration heavy coated electrode* extensively used throughout Europe.

Soudométal's representative—P. LaGrange—can be reached at Sheraton Hotel in St. Louis, Mo.—during AWS Spring Meeting.

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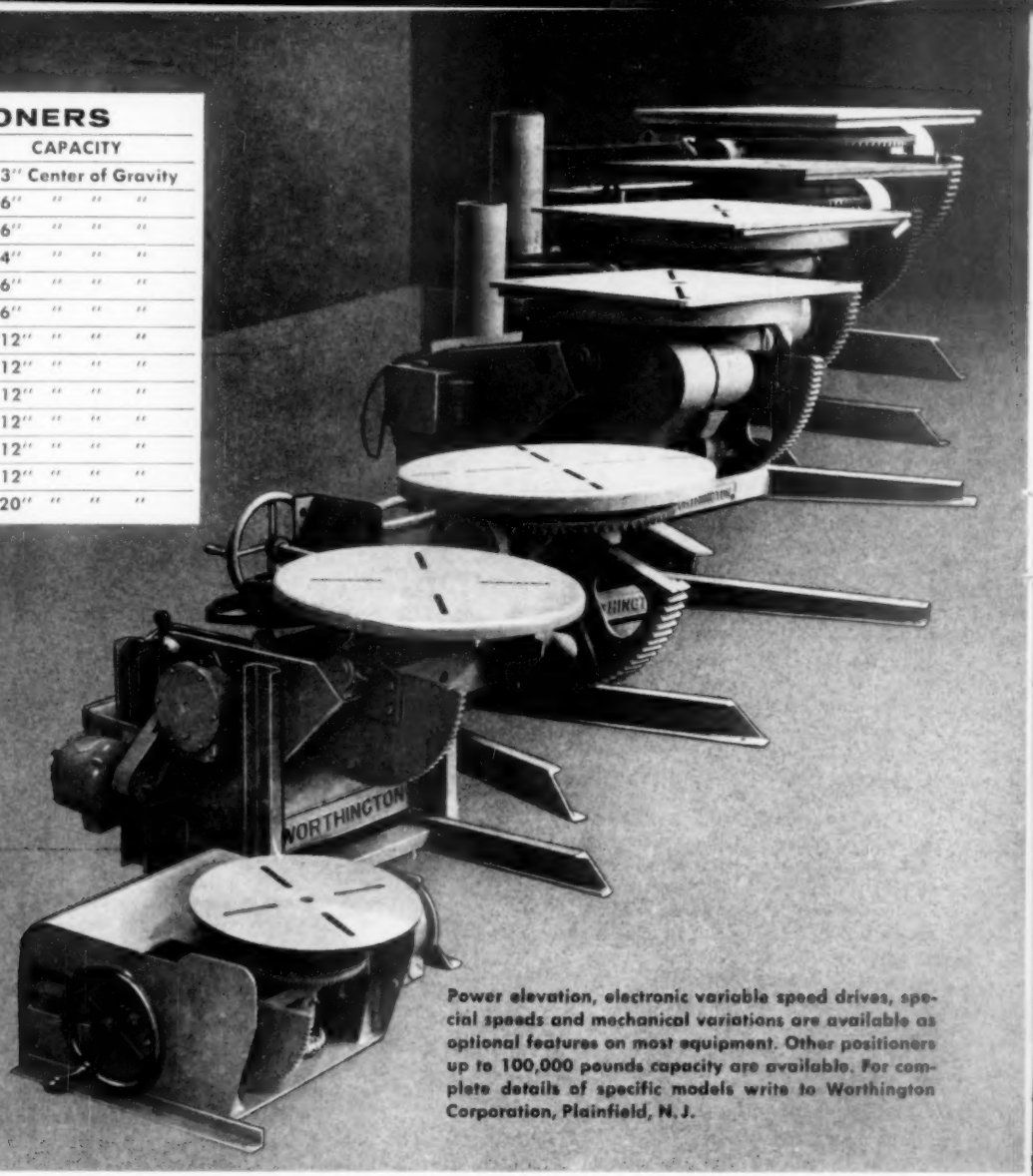
POSITIONERS

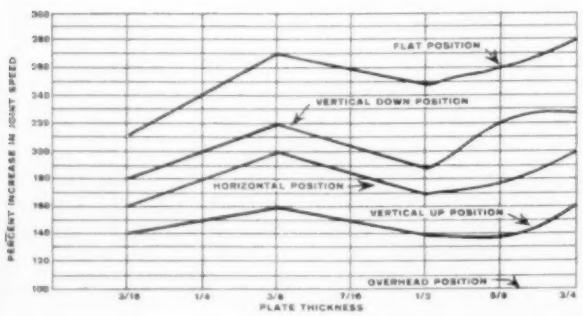
MODEL	CAPACITY
1P	100 lb. @ 3" Center of Gravity
5H	500 lb. @ 6" " " "
5P	500 lb. @ 6" " " "
10P	1000 lb. @ 4" " " "
25H	2500 lb. @ 6" " " "
25P	2500 lb. @ 6" " " "
30P	3000 lb. @ 12" " " "
60P	6000 lb. @ 12" " " "
100P	10000 lb. @ 12" " " "
160P	16000 lb. @ 12" " " "
240P	24000 lb. @ 12" " " "
400P	40000 lb. @ 12" " " "
600P	60000 lb. @ 20" " " "



Power elevation, electronic variable speed drives, special speeds and mechanical variations are available as optional features on most equipment. Other positioners up to 100,000 pounds capacity are available. For complete details of specific models write to Worthington Corporation, Plainfield, N.J.

INCREASE WELDING

with positioning equipment from



With a positioner you can often drastically reduce the cost of welding and work handling operations.

As the chart shows, joint speed in the downhand position is up to 280% faster than the other positions. With a positioner you always weld "downhand." Without a positioner it often takes more time and labor to handle the weldment than it does to actually weld the piece.

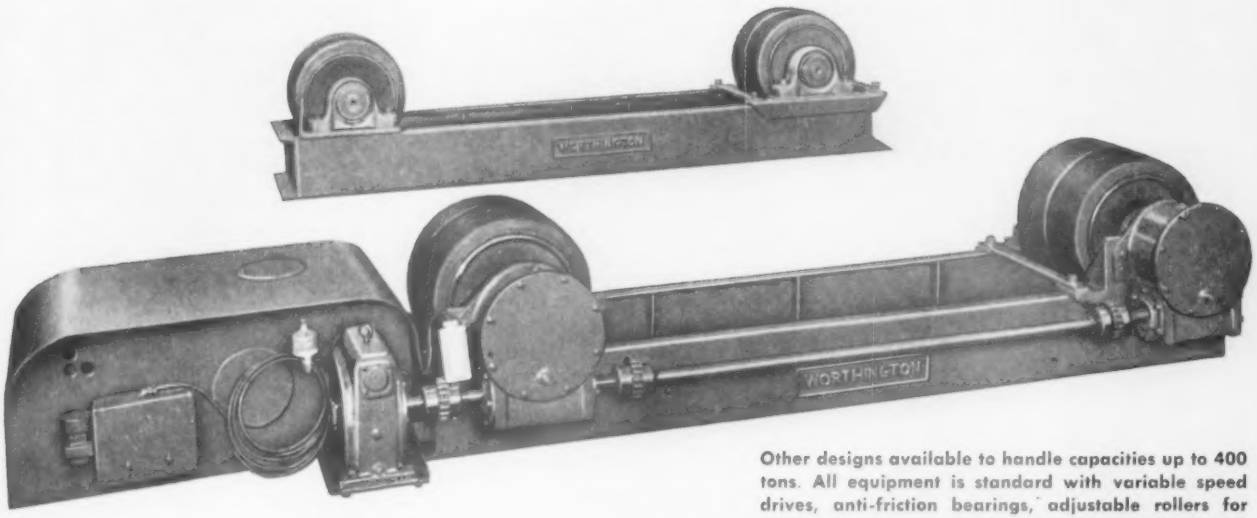
WHY WORTHINGTON?

There are many reasons why more welding is done on Worthington positioners than all others combined. One is

For more details, Circle No. 62 on Reader Information Card

TURNING ROLLS

MODEL	TURNING CAPACITY		WEIGHT CAPACITY PER UNIT	
	METAL ROLLERS	RUBBER ROLLERS	METAL ROLLERS	RUBBER ROLLERS
A	9 tons	6 tons	3 1/2 tons	2 tons
AA	10 tons	10 tons	5 tons	3 1/3 tons
B	50 tons	30 tons	12 1/2 tons	10 tons
C	100 tons	60 tons	20 tons	20 tons
D	180 tons	90 tons	30 tons	30 tons



Other designs available to handle capacities up to 400 tons. All equipment is standard with variable speed drives, anti-friction bearings, adjustable rollers for varying diameters, and electric remote push button for forward and reverse rotation. Optional features include tachometer and electric remote variable speed control.

Worthington turning rolls are also available in self-propelled models offering power driven and idler cars for power and idler rolls. For complete specifications write to Worthington Corporation, Plainfield, N.J.

SPEED UP TO 280%

Worthington's complete line

good service. With distributors in all principal cities a Worthington positioning specialist is nearby to help solve your welding problems.

Conservative ratings are another. Worthington engineers its positioners to deliver year after year the rating stamped on the nameplate. And Worthington brings the industry's broadest background of experience and know-how to bear on your positioning problems. Conceived in the fabricating shop of Ransome Machine Co.—later to become a division of Worthington—positioners were pioneered by Worthington people for more than 25 years.

Let us help you increase welding speed up to 280%. For descriptive information on Worthington's line of positioners, automatic welding head manipulators, turning rolls, and head and tailstocks, write to Section Y-76, Worthington Corporation, Plainfield, New Jersey.

WORTHINGTON

See Worthington's all new 1958 line of Manipulators: new Model 240 precision electronic positioner and Model "O" one ton capacity turning roll at the AWS Show, Kiel Auditorium, Booth 300, St. Louis, Mo.

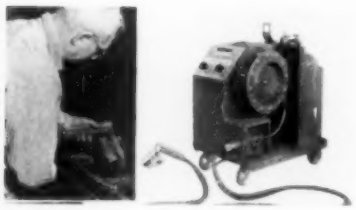
For more details, circle No. 62 on Reader Information Card

NEW PRODUCTS

Semiautomatic Submerged-Arc Welder

A new type of mechanized welding machine for the submerged-arc process has been introduced by the Lincoln Electric Co., Cleveland, Ohio. The new machine, the Lincolnweld ML-3, is a mechanized unit which provides automatic wire feed, flux flow and travel speed, but permits manual guiding of the welding arc. The unit feeds a continuous wire electrode from a coil to a compact hand-held gun which is positioned against the joint and is propelled at a preset speed by a small motor. A low pressure air system flows flux from a large tank to the gun from which it drops to cover the arc completely.

The features of the new machine are



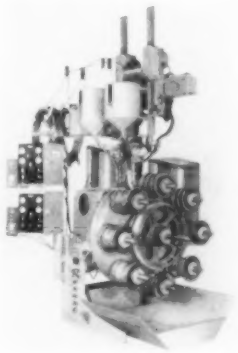
intended to improve the application of the submerged-arc process, extending its use and reducing the cost of many jobs now being welded by hand with conventional coated electrodes. Speeds up to 70 ipm using up to 600 amp are reportedly possible with this manual, mechanized unit. According to Lincoln, the unit can weld minimum thicknesses from 10 gage to heavier materials, a feature which provides flexibility.

The mechanized travel speed is supplied by a small d-c motor mounted on the nozzle end of the welding gun. The gun is an L-shaped tube, approximately 1½ in. in diam. The handle part of the tube is 7½ in. long; the nozzle end of the tube is 5½ in. long. The motor drives a knurled steel wheel that rides the work and propels the gun at any preset speed.

For more details, circle No. 64 on Reader Information Card.

Roller and Idler Unit

A new twin head automatic roller and idler welder and positioner, reportedly capable of mounting eight tractor rollers and one idler at a time, is announced by the Sight Feed Generator Co., West Alexandria, Ohio.

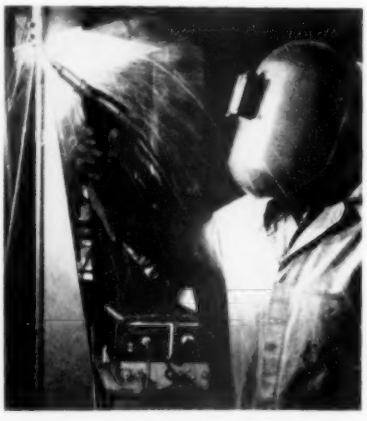


This new welding machine, the Rexarc MS-8, builds up both sides of the worn tractor rollers simultaneously and automatically. By the time the first roller (hard surfaced) reaches the eighth index position, it is sufficiently cooled to receive the second welding pass. Only one spindle turns at a time, and rotates only when in the welding position. According to the manufacturer, only a few seconds of time are required to rotate the turret from one welding position to the next. Welding heads are not moved out of position for indexing operations.

For more details, circle No. 65 on Reader Information Card.

Inert-Gas-Shielded Equipment

Air Reduction Sales Co., a division of Air Reduction Co., Inc., 150 E. 42nd St., New York 17, N. Y., is introducing a new manual unit for the application of its Aircomatic or inert-gas-shielded arc-welding process.



According to Airco, the assembly provides a new type of wire feeding system to handle the broadest range of wire types and sizes from the finest to the heaviest.

This development makes possible the selection of a variety of special purpose components to form a complete assembly consisting of a gun, its fittings, a wire feeder, a control panel and hoses and cables to carry cooling water and shielding gases. In the new model, both "push" and "pull" guns are available to cover the complete range of wire types and sizes from 0.020 in. hard to ⅛-in. aluminum. The equipment is portable.

For more details, circle No. 66 on Reader Information Card.

Electrode for CO_2 Welding

Production of "NCG 111-A" spooled electrode has been announced by the NCG Division of National Cylinder Gas Co., Chicago, Ill., adding "multi-pass versatility" to the company's "dual shield" carbon dioxide welding process.

The new electrode is reported to meet the requirements for both multiple and single-pass welding of pressure vessels under ASM-AWS and ASME codes. Like the standard single-pass electrode NCG-110 for "dual shield" welding, NCG-111-A is a flux-cored electrode that successfully welds all carbon steels up to 0.35% carbon content, and A8212 type steel.

NCG spokesmen say that "dual shield" welding is from three to twelve times faster than manual stick electrode welding and greatly simplifies welder training. The process, with inexpensive carbon dioxide acting as shielding gas and contributing actively to the welding reaction, cleans metal as it welds, reduces rejects, deposits over 99% of the electrode metal in the weld, gives the welder complete arc visibility and creates a self-removing slag.

For more details, circle No. 67 on Reader Information Card.

Kaiser Introduces New Gas-Shielded Techniques

Three new inert-gas-shielded metal-arc welding techniques for aluminum

have been developed by the Department of Metallurgical Research of Kaiser Aluminum & Chemical Corp., 1924 Broadway, Oakland 12, Calif.

The first, named "Qualiweld," was developed to produce consistently high quality welds by reducing porosity and dross. In this process the inert-gas-shielded metal-arc welding gun is modified so that a mixture of argon and chlorine can be introduced down the contact tube directly into the inner core of the arc, and thereby eliminate the effects of contaminants. There are no harmful effects upon the operator because the chlorine used represents only a small fraction of 1% of the total shielding gas. Minor protective measures insure no corrosion damage to equipment.

In another technique, "Economeld," nitrogen replaces inert gas in the shielding atmosphere, and low-flow inert gas is used in the contact tube. This process is best adapted to low-cost welding of bus bar and other low-alloy aluminum sections.

The third technique, "Chlorecon," is a low cost, code quality inert-gas-shielded metal-arc process usable on all weldable aluminum alloys and in all welding positions. This technique employs a low flow of inert gas such as argon containing a small amount of chlorine down the contact tube with a low flow of inert gas through the nozzle in the outer shield. With Qualecon, code quality welds meeting all bend tests can be achieved with high quality commercial filler wire.

These processes are covered by patent rights of Kaiser Aluminum & Chemical Corp.

For more details, circle No. 68 on Reader Information Card.

Nickel-Base Brazing Alloy

A new high-temperature service brazing alloy for higher strength and oxidation resistance applications where erosion must be controlled is now available from Stainless Processing Division of

Wall Colmonoy Corp., 19345 John R. St., Detroit 3, Mich.

Close laboratory control and use of virgin metals assure uniformly high quality in foot after foot of this new, versatile rod for . . .

1. Brazing and braze-welding steel, cast iron, malleable iron, copper and its alloys with the oxy-acetylene process.
2. Building up bearing, wear- and corrosion-resistant surfaces on steel and cast-iron parts.

Smooth, dense, free-flowing deposit has excellent tinning action. You get welds with up to 60,000 psi. ultimate tensile strength on high-strength manganese-bronze base plates — and up to 50,000 psi on steel base plates. Overlay deposit hardness on steel or cast iron is 80-110 BHN (500 kg.)

Order Ampco-Brāz #2 from your nearby Ampco distributor. He has it in 1/16", 3/32", 1/8", 3/16", 1/4", 5/16", and 3/8" diameters.

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AMPCO-BRāZ FLUX #2
New — for general brazing, and cast-iron welding and brazing. Cuts costs, saves time. Has many advantages:
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Excellent wetability.
Depresses filler-metal bubbling and fuming.
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Protects against excessive oxidation.
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Send me Bulletin W-17 for further information on Ampco-Brāz #2 and other Ampco electrodes.

Name.....
Company.....
Address.....
City.....Zone.....State.....
W-147

For more details, circle No. 69 on Reader Information Card

Designated Nicrobraz 150, the new brazing alloy is a nickel base material containing chromium borides suited for use in the fabrication of such parts as turbine blades, rotor shafts and highly stressed sheet metal structures. It is available in the form of powder, rod, paste or plastic bonded wire.

For more details, circle No. 70 on Reader Information Card.

Titanium Fittings Forecast

Plans to offer a complete line of welding fittings and flanges of commercially pure grades of titanium to match every schedule and size of titanium piping now made were announced in Louisville, Ky. by Tube Turns, a division of National Cylinder Gas Co., Chicago.

"The decision reflects the development of improved forging techniques, declining costs of titanium and encouraging sales development forecasts," according to John G. Seiler, Tube Turns president. "The 1957 slowdown in aircraft orders and an increased productive capacity have made the metal widely available now for commercial applications," he said. "Many industries—notably chemical processing, anodizing, petroleum, marine and food processing—are not active in development of private industry uses of titanium piping."

For more details, circle No. 101 on Reader Information Card.

Helmet Bib and Gloves

John Tillman & Co., 1561 W. 19th St., Long Beach 10, Calif., have released catalog sheet No. 11 which describes two new products manufactured by the firm. The first is a helmet bib which can be attached without separate application to the helmet. Special spring-type

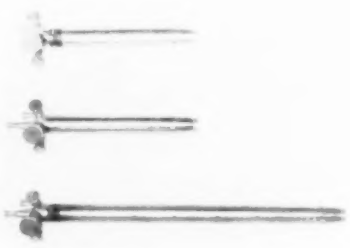
fasteners can reportedly be applied to secure the bib to most hard helmets.

A cowhide glove is also described which is made from soft, tan Auburn brown leather and, according to the manufacturer, is designed to provide long service.

For more details, circle No. 71 on Reader Information Card.

Machine Cutting Torch

A new series of machine cutting torches, with both straight bore and divergent type cutting tips, are now available from Air Reduction Sales Co. a Division of Air Reduction Co. Inc., 150 E. 42nd St., New York 17, N. Y. Designed for



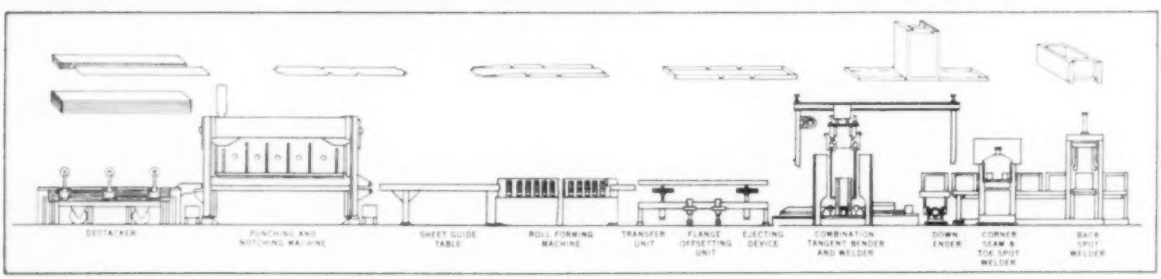
use with natural gas, city gas, propane and liquefied petroleum gases, this equipment operates under either low or positive pressure.

Designated as Style 2500 machine cutting torches, there are two- and three-hose models. One model is used on Travographs, Oxygraphs and Duographs (multiple-torch flame-cutting machines), and two models are for use on Radiagraphs, Camographs, Monographs and pipe-cutting and bevelling machines.

The straight bore type tip (obtain-

EXPLORE

production economies possible by combining: assembly, metal forming and welding.



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A W S WELDING SHOW

COMPLETELY AUTOMATED METAL FORMING AND WELDING LINES

This is representative of the completely integrated lines now built by T-W, who also offers the largest selection of standard and specially designed resistance and arc welding machines. Taylor-Winfield's line now includes the metal-forming and work-handling equipment formerly built by Struthers-Wells. Call your nearby T-W representative for specialized help in improving your production rate and quality.

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STAMFORD
OAKVILLE AND WINDSOR, ONTARIO

For more details, circle No. 72 on Reader Information Card

- NUB diameter automatically sets welding gap for root pass.
- Robvon Backing Rings Form perfect welded-joints eliminating slag and icicles.
- Robvon Backing Rings Allow complete penetration and fusion.
- Robvon Backing Rings Eliminate the necessity of tack welding.
- Robvon Backing Rings Radiograph perfect certified welds.

ROBVON BACKING RINGS

APPROVED FOR WELDED PIPE, VALVES, AND FITTING JOINTS

Available in carbon steel, wrought iron, chrome alloys, stainless steel, aluminum and copper

TYPE CCC Designed for quick easy alignment of pipe where the variation in inside diameters is relatively great. Chamfered NUBS allow close tolerance fit-up and CLEAN STRIKE OFF. The ROBVON NUB automatically sets root gap. ROBVON rings are beveled to assure non-restricted fluid flow.

TYPE CC Designed to allow quick easy alignment of pipe where the inside diameters are slightly out of round. The welder has the choice of "STRIKING OFF" the NUBS or leaving them intact to be melted into the weld mass of the first root pass.

TYPE C Designed for precise close tolerance fit-up. Type "C" NUBS automatically sets root gap. The NUBS melt with the metal to give complete penetration and fusion.

Robvon also manufactures machined rings to customer's specifications
All fabricated solid machined rings x-rayed. Write for full information

See us at the AWS Show—St. Louis, Booth 139

ROBVON
BACKING RING COMPANY

675 GARDEN STREET ELIZABETH, NEW JERSEY

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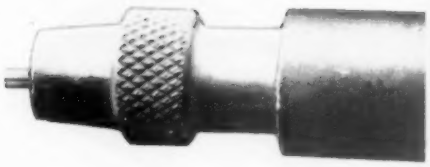


NEW

WEST·ING·GUN

Cuts Welding Costs! Speeds Production!

GETS EVERYWHERE!

Hard-to-weld Metals Now Welded Automatically! There is now a portable hand gun—for gas-shielded welding of aluminum, mild and stainless steels, bronze, copper and magnesium! Moreover, this hand gun has its *own self-contained wire supply!*

It is named the WEST-ING-GUN. It works with any standard DC welding machine. It has *averaged* horizontal fillets of 22 inches-per-minute—with $\frac{1}{16}$" wire! Throughout *extensive* field tests, this WEST-ING-GUN has *doubled men's daily output!*

OPERATOR FATIGUE "ELIMINATED"! This WEST-ING-GUN "handles" as easily as pointing your finger, to weld in *any* position—regardless of cramped quarters! Its portability between gun and control—between control and power-source—provides complete working freedom and ease—up scaffolding—atop ladders—all around any type of workpiece. This gun weighs only four pounds—including its full, pound reel of wire! Operators working a steady 30% duty cycle, with WEST-ING-GUNS, say they "feel no fatigue at all"!

Welding Remote from Power Source!

20-lb control is readily carried up superstructures! Every shipyard visited, during field-tests, immediately ordered WEST-ING-GUNS!

Time Saved in Tight Quarters!

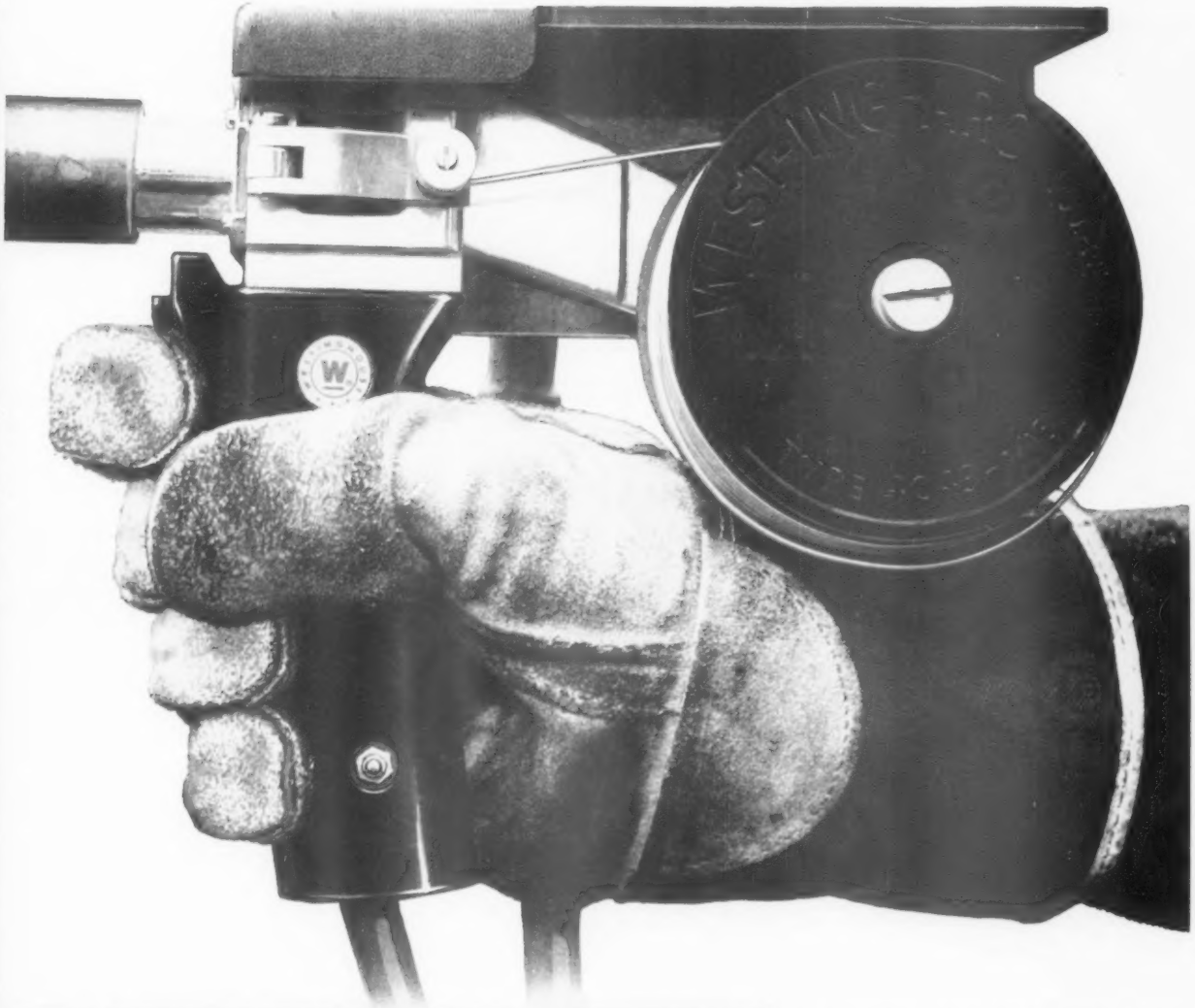
Weld wherever you please! Power and shielding gas are in a single-hose assembly. This permits access to heretofore "impossible" locations!

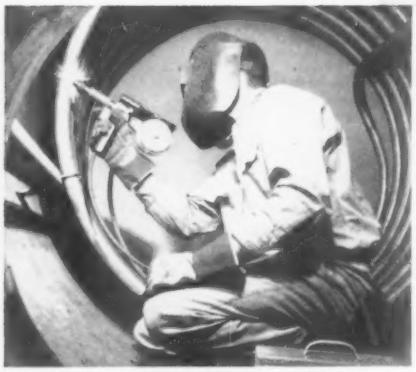
New Welding Speed on Big Units!

You can take the gun wherever you want to weld! The control stays with the machine! One man can now do the work that used to require two!

Watch Westinghouse for New Developments

For more details, circle No. 77 on Reader Information Card





Maintenance Welding Simplified!

WEST-ING-GUNS and lightweight control units do the job quickly! Invaluable as a time- and cost-saving production tool!

Aircraft Quality Welds Every Time!

Difficult welds are readily completed with new ease—in production of aircraft equipment—often well back into normally inaccessible areas!

in Welding

A unique, gear-head replaceable mechanism in the handle drives $\frac{1}{16}$" wire up to 350" per minute (finer wire *twice* as fast)! Wire is "inched" at the touch of a button. The short, 6" travel eliminates wire-feeding problems!

There are WEST-ING-GUNS and the controls available—for any DC welders. The compact, rugged control-unit for each model weighs less than 20 pounds. Virtually *every* welding shop has *countless* applications where WEST-ING-GUNS will save *appreciable* amounts of money!

Avail yourself of the opportunity to see what this new production tool can do for you! Contact your nearest franchised Westinghouse Welding Distributor; or write to the Westinghouse Welding Laboratories, Box 2025-A, Buffalo 25, New York.

J-22199

For more details, circle No. 77 on Reader Information Card

able in 7 sizes) is for cutting steel up to 16 in. thick, while the divergent type tip (with a range of 8 sizes) is for cutting steel up to 8 in. thick.

For more details, circle No. 73 on Reader Information Card.

Safety Goggles

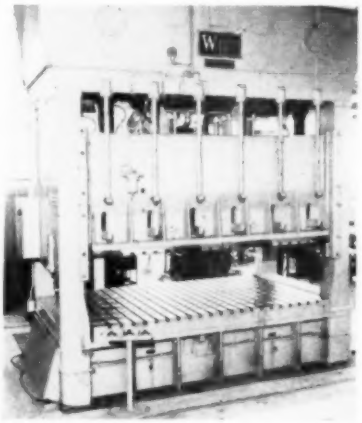
"Softie" coverall goggles, in both welder's and chipper's models, are now being introduced to the industrial safety equipment field by Glendale Optical Co., Inc., Valley Stream, Long Island, N. Y. Model GW-400, for welders, has light-proof indirect ventila-

tors to eliminate harmful light rays and glare and is fitted with removable rings and Glenweld filter lenses. Model GC-400, for chippers, is similar in style to the GW-400 except that direct ventilation and clear frame are provided.

For more details, circle No. 74 on Reader Information Card.

Gear Press

For press work done high up on the stroke (production runs of deep drawn parts) the Federal Machine and Welder Co., Warren, Ohio, has designed a welded steel, double back geared, four-point eccentric gear press for one of the nation's leading aircraft manufacturers.



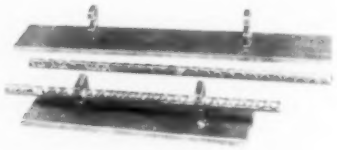
The press, especially designed for maximum rigidity and strength in frame and drive, has a capacity ½ in. from bottom of stroke of 300 tons. The frame is of the steel tie rod type. Distance between gibs is 137 in. The area of the slide is 90 x 136 in., with a stroke of 18 in. The press operates at 14 strokes per minute. It is equipped with a Wareo pneumatic clutch and brake with electrical clutch control. It requires approximately 96 x 190 in. of floor area and weighs approximately 192,000 lb.

Complete line of these presses has been designed in single point, two point and four point, in sizes from 100- to 2000-ton capacities.

For more details, circle No. 75 on Reader Information Card.

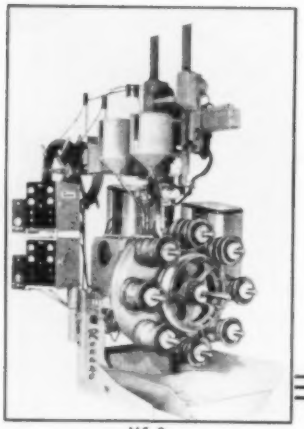
End-Welded Stud

Installation of reinforcing bar up to ⅞-in. in diam is said to be speeded with



a new end-welded stud, specifically designed for guniting and other concreting applications by the Nelson Stud Weld-

SPEED UP CRAWLER PARTS REBUILDING WITH *Rexarc* AUTOMATION



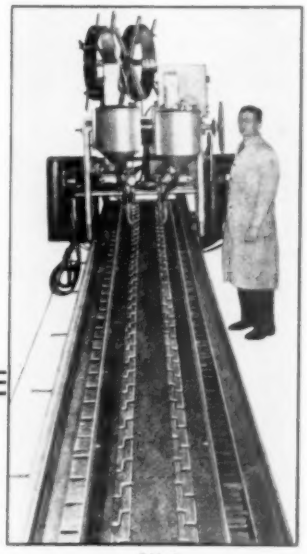
MS-8

Rexarc MS-8 Twin Head Tractor Roller and Idler Rebuilder

- Hard-faces both sides of rollers simultaneously
- Mounts 8 rollers and one idler at a time
- Write for free literature

Rexarc RM-6 Twin Head Tractor Track Rebuilder

- Hard-faces both sides of track simultaneously
- Skips spaces between links
- Ready for rugged service



RM-6

See these new machines at our Booth No. 135, AWS Show St. Louis, April 15-17

Manufactured by

THE SIGHT FEED GENERATOR COMPANY
WEST ALEXANDRIA, OHIO

For more details, circle No. 76 on Reader Information Card

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Magnet Wire • Lead Wire • Power Supply Cords, Cord Sets and Portable Cord • Aircraft Wires
Welding Cable • Electrical Household Cords • Electronic Wires • Automotive Wire and Cable

For more details, circle No. 84 on Reader Information Card

ing Division of Gregory Industries, Inc., Lorain, Ohio.

According to Nelson, the new rectangular "Re-Bar" stud cuts costs of securing reinforcing bar to steel surfaces by eliminating both hand welding of fasteners and tying of bar. Studs are end-welded, the bar is placed in a "jaw" of the stud and is then locked into place with a couple of hammer blows.

In standard dimensions, the new stud, designated Type R4L, measures $\frac{3}{4}$-in. wide and $\frac{3}{16}$-in. thick. The recommended minimum distance from the weld base to the edge of the "jaw," which is the distance the bar will be held away from the steel, is $\frac{7}{16}$-in. Studs may also be obtained with this dimension as $\frac{11}{16}$, $\frac{15}{16}$, $1\frac{3}{16}$ and $1\frac{7}{16}$ in.

For more details, circle No. 78 on Reader Information Card.

Safety Glasses

Plastic and metal frame safety glasses have been introduced by the Chicago Eye Shield Co., 2727 W. Roscoe St., Chicago, Ill. Given the name "Cesco Comfort Bridge Stylist Safety Glasses," the new open-type frame is reputed to reduce safety equipment costs by providing a durable, long-wearing frame in which lenses can easily be replaced.

The new safety glasses are offered

with the F-7 shaped lens in clear Super-Safety No. 1 and Antiglare Super-Safety No. 2 glass or in clear Cesolite plastic. Made of polyethylene, pads are reportedly light and comfortable on the nose and conform to the different contours of the nose.

The glasses are available in 46 × 39 mm and 48 × 41 mm eye sizes. Bridge sizes are 20, 22, 24 and 26 mm. Lenses offered in 6.00 curve only.

For more details, circle No. 79 on Reader Information Card.

Safety Technique

A technique to encourage safety among workers has been introduced by Industrial Glove Division, Riegel Textile Corp., Conover, N. C.

Safety slogans printed across the backs or cuffs of all Riegel industrial gloves are now standard procedure. This added feature is done at no extra charge.

For more details, circle No. 80 on Reader Information Card.

Equipment Chest

A practical new all-steel chest for holding and protecting welding equipment in the shop, on the truck and out on the job, has been introduced by Atlas Welding Accessories, Inc., 707 E. Lewis-

ton Ave., Ferndale 20, Mich. and is now available through dealers.

The chest is $8\frac{1}{2}$ x $16\frac{1}{2}$ x $24\frac{1}{2}$ in. and has reinforced corners, heavy latches, lock and carrying handle. It holds over 100 ft of hose, oxygen and acetylene regulators and cutting and welding torches.

A smaller chest is built into the center which may be opened without removing larger equipment. It holds goggles, lighter, extra tips, chalk, etc. The lid of this box is cut out for holding and protecting the regulators.

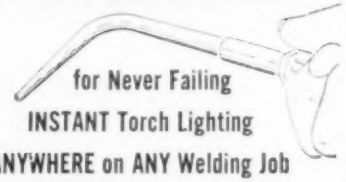
For more details, circle No. 81 on Reader Information Card.

Multi-Spot Welder

Among new special automation welders designed by Acme Electric Welder Co., 2618 Fruitland Ave., Los Angeles, Calif., is a multi-spot welding machine for high-production welding of paper towel dispensing units.

According to the manufacturer, the unit has an air-operated expanding mandrel and an automatic gun-shuttling unit which automatically sequences for four welding operations. Positioning of the parts on the welding mandrel automatically selects the guns and transformers for the welding cycle. This is accomplished by small limit

--and NOW a Battery Operated TORCHIE



for Never Failing
INSTANT Torch Lighting
ANYWHERE on ANY Welding Job

- No More Flints
- No Loss of Time
- Magnetically Held on ANY unpainted Metal Surface
  - Steel Girders
  - Tanks
  - Pipelines
  - Boilers, etc., etc.

Once you try this ALL NEW Battery Operated TORCHIE, you'll wonder how you ever got along without one. Soon saves its costs in flints alone. Only $9.95. Plug in Torchie 110 volts—7 watts, for bench operation—same price. Your Welding Supply Dealer will let you try one on 30 days guarantee. See him TODAY!

THERMACOTE COMPANY
108 S. DeLacey St. Pasadena, Calif.

Circle No. 82 on Reader Information Card

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Garments

For Cool Wear Use MITTENS

For Long Wear Use TILLMAN PRODUCTS

BRAZILIAN DEERSKIN
THE "STAY SOFT" LEATHER

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TILLMAN PRODUCTS

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LONG BEACH, CALIF.

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Magnetic? OR Electronic? WELDER CONTROL — WHICH WILL DO YOUR JOB BEST?

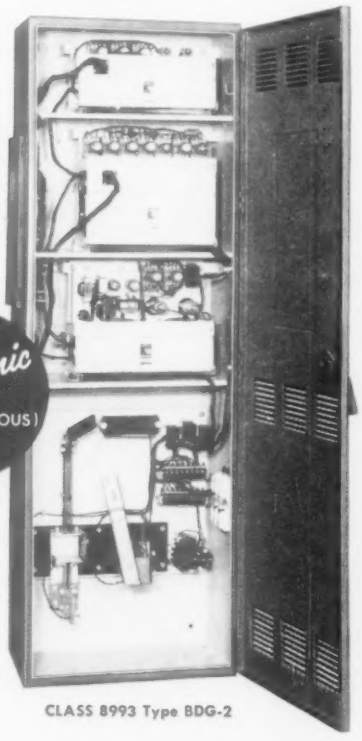
Square D makes them all... for simplest or most exacting applications!

Magnetic

for General Purpose Machines

For applications requiring widely varying welding conditions, normal welding speeds and maximum simplicity.

CLASS 8992 Type BBG-1



Electronic (SYNCHRONOUS)

for Precision Welding

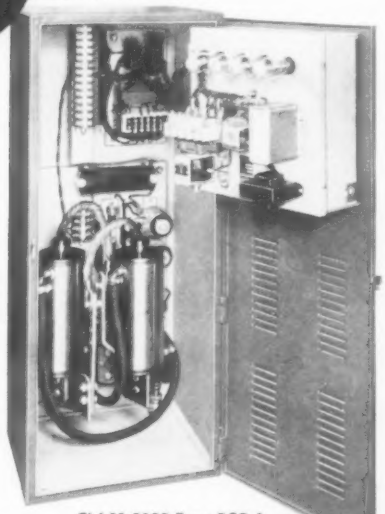
For welding aluminum, other non-ferrous and ferrous metals requiring precision weld times; stepless heat control; slope or taper control.

CLASS 8993 Type BDG-2

Electronic

for High Speed Welding

For production line (gun or stationary) welders and other applications where high speed, high currents or dual gun control are factors.



CLASS 8992 Type BCG-1

You'll find your nearby **Square D Field Engineer** *a source of sound counsel in selecting the welder control best suited to your application.*

NOW...EC&M PRODUCTS ARE A PART OF THE SQUARE D LINE!

SQUARE D COMPANY

For more details, circle No. 91 on Reader Information Card

switches which are located in the welding dies.

Electrode force is developed by an Acme air-hydraulic booster which transmits hydraulic fluid to the welding guns.

This welder is equipped with two 50-kva transformers which are fired in sequence to minimize kva demand.

For more details, circle No. 85 on Reader Information Card.

Nuclear Welding Torch

Vacuum Specialties Co., Inc., 34 Linden St., Somerville 43, Mass., have introduced an automatic welding torch and control system for high-purity atmosphere welding. According to the manufacturer, the torch was designed to

meet the critical standards of thin gage nuclear-fuel element welding, both subassemblies and finished elements. It is said to be suitable for other applications in the automatic welding of zirconium, zircalloy, titanium, molybdenum or other reactive metals.

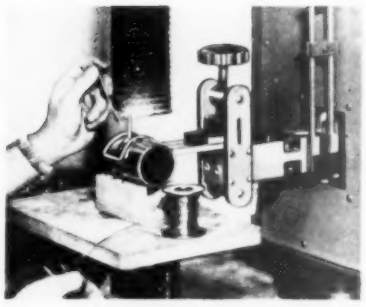
For more details, circle No. 86 on Reader Information Card.

Induction-Heating Coil

An innovation for users of high-frequency induction heaters in the welding field was recently announced by the L. C. Miller Co. of Los Angeles.

Trade-marked Miller Re-Coil, it reportedly standardizes and simplifies the interchange of work coils.

The product is a terminal assembly and is available in models to fit any induction heater. It remains in a fixed

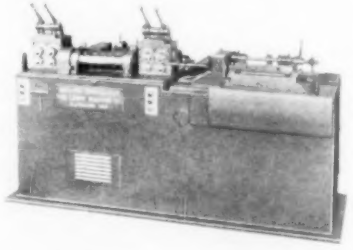


position and contains all operations and fixtures within it.

For more details, circle No. 87 on Reader Information Card.

Wire-Cutting Machine

Lewis Machine Co., 3441 76th St., Cleveland, Ohio, announces a new machine for the high-speed cutting of commercial welding rod and similar short items. This is the Number 4FH "Travel-Cut" of the new "FH" high-speed



series of Lewis automatic "Flying-shear" wire straightening and cutting machines. According to the manufacturer, the capacity of the 4FH in mild steel is $\frac{5}{32}$ to $\frac{1}{4}$ in. in diameter, while high-carbon, alloy and stainless steels: $\frac{3}{16}$ in. maximum.

For more details, circle No. 88 on Reader Information Card.

Stud Welding

Shielded Stud Welding Co., 1540 Seabright Ave., Long Beach 13, Calif., announces a new type of welding stud and ferrule, under patents pending. According to the manufacturer, the stud contains no flux, using instead a small tip which initiates the arc.

For more details, circle No. 89 on Reader Information Card.

Production Soldering

A new process for standardization and quality control in production soldering applications was recently announced by Fusion Engineering Co., 17921 Rosedand Ave., Cleveland, Ohio.

Procedures for standardization and

THEY
LOOK
ALIKE...
BUT THERE'S A BIG DIFFERENCE INSIDE
... AND THERE'S A BIG DIFFERENCE INSIDE ACETELYNE CYLINDERS, TOO. ONLY COYNE BRINGS YOU THE MAGIC MONOLITHIC FILLER LIGHTER—MORE ABSORBENT—FASTER FILLING FOR QUALITY—TO THE CORE—PICK COYNE
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24 COMMERCE STREET, NEWARK, N. J.
For more details, circle No. 90 on Reader Information Card

IMPORTANT ANNOUNCEMENT To Users of Cutting Machines

These widely-renowned oxygen cutting machines feature a distinctive construction and an engineered system of operation. With them, you can now achieve new standards of accuracy in precision workmanship. Write for full details!

NEW SALES MANAGER NAMED

Richard L. Deily has been appointed Sales Manager for Messer Cutting Machines. He is a graduate of Lehigh University. His 20 years' experience in the cutting machine and welding fields includes positions with some of the largest firms in the metal-working industry. May he consult with you on improved cutting techniques?

AMERICAN MESSER CORPORATION WILL NOW HANDLE AND SERVICE THE WORLD-FAMED

MESSER CUTTING MACHINES

"THERE IS NO SUBSTITUTE FOR MESSER EXPERIENCE"

AMERICAN MESSER CORPORATION

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PRECISION CUTTING MACHINES...OXYGEN, NITROGEN, ARGON PLANTS

For more details, circle No. 97 on Reader Information Card

quality control are based on the use of Fusion's latest paste-type solders, (incorporating solder powder with special fluxes and neutral binders), and newly developed automatic and semiautomatic dispensers. In this process, a metered amount of paste solder is preplaced inside the joint area. The solder may take the form of a dot, a stripe, or a pattern as required. Amounts as small as one four-hundredth of an ounce of material can be metered exactly through more than a million cycles with no appreciable variation. After preplacing the solder inside the joint area, the parts are passed through a controlled heating cycle and allowed to cool, thus completing the soldering operation.

For more details, circle No. 92 on Reader Information Card.

Nickel Electrode

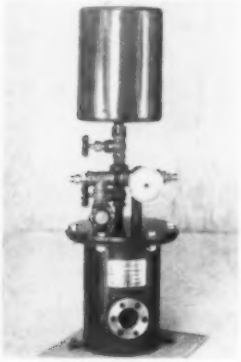
Welding Equipment & Supply Co., 5225 E. Davison, Detroit 12, Mich., announces the availability of Eureka No. 100 pure nickel electrodes.

According to the manufacturer, the metallic coating on the No. 100 nickel allows welding on finished and polished areas of castings without the danger of arcing through the coating, thereby allowing welding on a finished surface.

For more details, circle No. 93 on Reader Information Card.

Liquid Flux

The Vap-R-Flux Corp., 198 Wayne St., Mansfield, Ohio, announces the availability of a liquid flux, called "Vap-R-Flux." Composed of pure chemicals and reportedly distilled to remove all moisture, "Vap-R-Flux" is said to set a protective cover over the

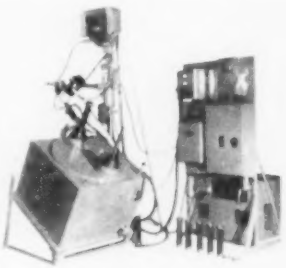


metal during the brazing and welding operation which eliminates oxide formations and atmospheric moisture from the weld. The manufacturer discloses that no special torches or tips are required, a liquid flux vaporizing unit attached to the fuel gas line being the only installation necessary.

For more details, circle No. 94 on Reader Information Card.

Automatic Welding Machine

Tri-City Tool & Machinery Corp., P.O. Box 404, Rock Island, Ill., has designed and built an automatic welding machine reportedly capable of welding collars on each end of a tube at the



rate of 360 welds an hour. According to Tri-State, a skilled welder is not required—the operator merely loads and unloads the parts used.

The welding unit is a General Electric of inert-arc type, using 0.045-in. electrode at 72 ipm.

For more details, circle No. 95 on Reader Information Card.

Welding Chamber

A welding chamber has been announced by L and B Welding Equipment, Inc., 2424 6th St., Berkeley 2, Calif., for welding fuel rod end caps, fuel channels, fuel tanks and other relatively large nuclear and missile components manufactured from materials requiring controlled atmospheres. It is reported

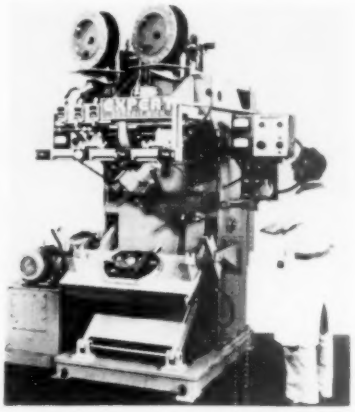
that this particular system is 36 in. diam, 90 in. long, ultimate vacuums and pump downtime as required and features rotational and longitudinal welding fixtures. Versatility is said to be offered, with the ability to attach airlocked presses and other equipment at a future time.

For more details, circle No. 98 on Reader Information Card.

Automatic Welding

A single-station automated welding machine that reportedly performs welding operations on the inside of tubular production parts by means of automation techniques is now available from Expert Welding Machine Co., 17144 Mt. Elliott Ave., Detroit 12, Mich.

The machine is said to produce linear-reinforcement welds on the inside



seam of the banjo section of rear-axle housings at a production rate of 250 pieces per hr. The machine is adaptable to production parts requiring short linear welds.

The welding process utilizes welding wire which has a tubular cross section. Flux needed for the welding operation is contained inside of the tubular wire. This method permits welding in small areas, where flux-depositing equipment would be difficult to use and where open-arc welding methods are less satisfactory.

For more details, circle No. 99 on Reader Information Card.

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TO
ATTEND

APRIL 15-16-17, '58
KIEL AUDITORIUM
St. Louis, Missouri

For more details, circle No. 100 on Reader Information Card →

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TEMPILSTIKS° provide a simple and accurate means of determining preheating and stress relieving temperatures in welding operations. Tempilstiks° are widely used as a standard method of checking temperatures in all heat treating—as well as in hundreds of other heat-dependent processes in industry. Available in 67 different temperature ratings . . . . . $2.00 each.

Most leading welding supply houses carry Tempilstiks°.

If yours is among the few that do not as yet, then write direct to us for further information.

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Visit Tempil° Booth No. 207—Welding Show—St. Louis, Apr. 15-17

Colmonoy Hard-Facing INCREASES PART LIFE

Colmonoy hard-facing alloys and methods are designed to make the metal parts of your product wear much longer—at the lowest possible cost.

Colmonoy nickel, cobalt, and iron base alloys provide a wide range of wear resistant qualities for maximum part life regardless of the type of wear. Available as electrodes, gas rods, castings, and Sprayweld Powder.

Colmonoy methods include The Sprayweld Process*, by which smooth, welded deposits of superior hard-facing alloy are easily sprayed on, saving material, time, and finishing costs.

Submit part drawings and a description of the wear encountered for a specific recommendation. Request Hard-Facing Manual No. 79.

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Circle No. 102 on Reader Information Card

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SPOT WELDING OF Ti-6Al-4V ALLOY

Systematic variation of machine settings and weld parameters employed to develop a satisfactory procedure for spot welding of Ti-6Al-4V high-strength alloy

BY R. K. NOLEN, J. F. RUDY, H. SCHWARTZBART AND H. D. KESSLER

ABSTRACT. A procedure for spot welding Ti-6Al-4V was developed by performing a systematic variation of weld parameters and machine settings and measuring the mechanical properties of the welds obtained. The resulting data were found to be comparable to recommendations for similar gages of stainless steel.

Having developed a welding schedule that produced satisfactory spot welds, the optimum machine settings obtained were used to study other geometrical effects such as minimum contacting overlap, shunting current, minimum spot weld spacing and electrode indentation.

A secondary phase, discussed in this paper, is concerned with a preliminary investigation of post-weld heat treatments to determine their effects on the cross-tension to tension-shear strength ratios of the as-welded joints. The data indicate that these ratios are increased slightly by employing post-weld heat treatments in the machine or heating with an oxy-acetylene flame.

Data are also presented on the elevated-temperature strength of spot welds, and the effects of exposure to air at elevated temperatures under load or no load on room-temperature strength.

Table 1—Chemical Analysis of Ti-6Al-4V

Sheet thickness, in.	*Heat no.*	*Alloying elements, %*						
		C	*Fe*	N_2	*Al*	*V*	H_2	*Ti*
0.035 / 0.063	M3890	0.010	0.12	0.009	6.2	4.1	0.012	89.5
0.070	M3078	0.02	0.16	0.009	6.1	4.1	0.009	89.5
0.062	M3889	Chemical analysis not available						

Table 2—Mechanical Properties of Ti-6Al-4V

Sheet thickness, in.	*Heat no.*	*Yield strength, psi*	*Tensile strength, psi*	*Elongation, %*	*Rockwell hardness no.*	*Cold bend—Press Brake*	
0.035	M3890	Long. 139,800 / Trans. 139,800	143,800 / 142,000	9.0 / 11.0	C 37	105 deg	−4T
0.070	M3078	Long. 127,720 / Trans. 136,250	137,400 / 143,300	10.0 / 13.0	C 50	105 deg	−4T
0.062 / 0.063	M3889 / M3890	Mechanical properties not available					

Introduction

Titanium and its alloys are enjoying greater demand as the required technology for their fabrication and application is rapidly being developed. One of the more popular high-strength alloys is Ti-6Al-4V which is finding use as a sheet material in the airframe industry.

The primary object of this investigation was to develop the recommended settings and parameters for the spot welding of this alloy. The initial machine settings at the beginning of the program were taken from the Resistance Welding Manual* recommendations for stainless steel since its electrical and thermal conductivities are similar to titanium. The parameters investigated were welding current, electrode pressure, electrode geometry, welding time, minimum overlap distance and minimum spacing for multiple spots. The weld-

R. K. Nolen, J. F. Rudy and H. Schwartzbart are associated with Armour Research Foundation, Chicago, Ill., and H. D. Kessler is associated with Titanium Metals Corporation of America, Toronto, Ohio.

Paper to be presented at the 1958 AWS Annual Spring Meeting to be held in St. Louis, Mo., April 14-18.

*"Resistance Welding Manual," Revised Edition. Resistance Welder Manufacturers' Association, Philadelphia 3, Pennsylvania (1948).

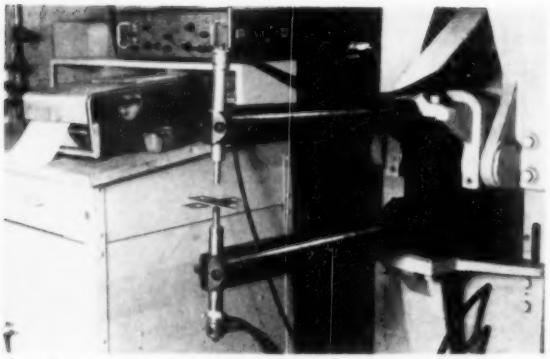


Fig. 1 30-kva, 60-cycle, single-phase spot-welding machine for welding the 0.035-in. sheet, showing the amplifier and oscillograph

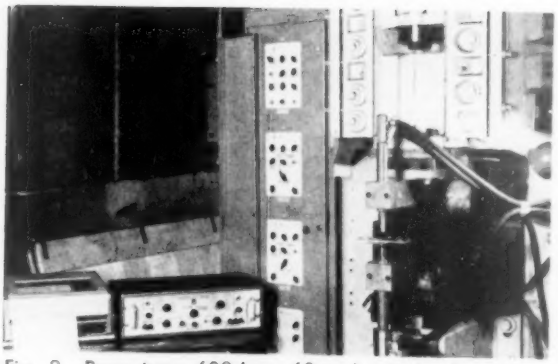


Fig. 2 Press type 600-kva, 60-cycle single-phase spot-welding machine with control unit, for welding the 0.062-, 0.070- and 0.093-in. thick sheets. Visible also are the amplifier and oscillograph

joint characteristics which were used as a measure of spot quality were weld strength, sheet separation, electrode indentation and weld nugget geometry. Post-weld heat treatments and weld stability at service temperature under stress were also studied.

Materials

The Ti-6Al-4V alloy was in sheet thicknesses of 0.035, 0.062, 0.070 and 0.093 in. The material was welded in the as-received condition with no special surface preparation except ordinary care to prevent grease stains and fingerprints. Tables 1 and 2 show chemical analyses and mechanical properties, respectively.

Apparatus and Equipment

Two spot-welding machines were utilized. The 0.035-in. sheet was welded with a 30-kva, 60-cycle, single-phase, 30-in. rocker arm type machine (Fig. 1). The three remaining thicknesses, 0.062, 0.070 and 0.093 in., were welded on a press type 600-kva, 60-cycle, single-phase machine (Fig. 2). The 30-kva machine was not used for welding the three thicker gages because the recommended pressures could not be obtained on this machine. The 600-kva machine is equipped with control over weld time, weld current, up-and-down slope, post-weld heat treatment and post-weld forge pressure.

A four-channel, direct pen-recording oscillograph was used to measure the various electrical parameters such as time and current for welding and post-weld heat treating. Figure 3 shows a pen trace of a typical up-and-down slope plus post-weld heat treatment.

Figure 4 shows the fixture used for testing cross-tension specimens. No special jig was required for tension-shear testing.

Experimental Procedure and Discussion

General Welding Schedule

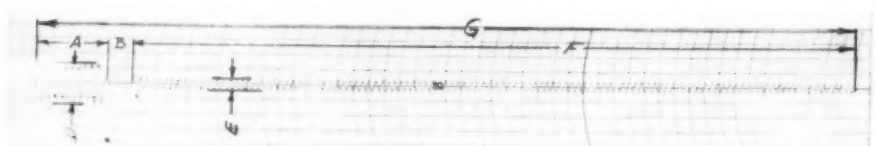
The procedure followed in investigating and establishing the welding parameters, such as electrode force, weld time, weld current and electrode geometry, etc., is discussed in this section.

The spot-welding schedule consisted of making three tension-shear specimens, two cross-tension specimens and one metallographic specimen for each thickness and set of welding parameters. The tension-shear specimens were welded from two 1½-in. × 3-in. strips, the cross-tension specimens were 2- × 6-in. strips and the specimens for metallographic examination were 1-in. squares. Table 3 lists each run made. Figures 5 and 6 show the type of tension-shear and cross-tension specimens used.

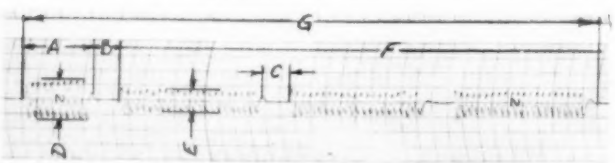
Electrode Geometry

Two electrode geometries were investigated, a 3-in. spherical face radius—⅜ in. diam, and a truncated cone—⅜ in. minor diam by ⅝ in. major diam type. The electrodes were RWMA Class 2 copper alloy, except for a limited number of tests made with a Class 3 alloy.

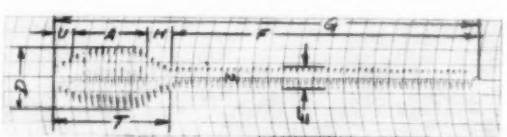
The 3-in. spherical-radius electrode gave better welds. During the welding program it was possible, using the 3-in. radius electrodes to obtain a wider range of current settings from the point of no-weld up to the point of metal expulsion. Also, higher weld strengths both in cross-tension and tension-shear with resulting higher ratios of cross-tension strengths to tension-shear strengths were accomplished by using the radius electrodes as compared to the truncated cone. This is illustrated in Fig. 7. Observation of metal-



(a) Trace showing cycles of weld time, quench time and continuous postweld heat treatment



(b) Trace showing cycles of weld time, quench time, cool time and intermittent postweld heat treatment



(c) Trace showing cycles of up-and-down slope, weld time and continuous postweld heat treatment

A, Weld time; *B*, quench time; *C*, cool time; *D*, weld-current amplitude; *E*, heat-treatment current amplitude; *F*, heat-treatment time; *G*, total welding and heat-treatment time; *H*, down-slope time; *U*, up-slope time; *T*, weld time plus up-and-down slope time

Fig. 3 Current traces as recorded by oscillograph

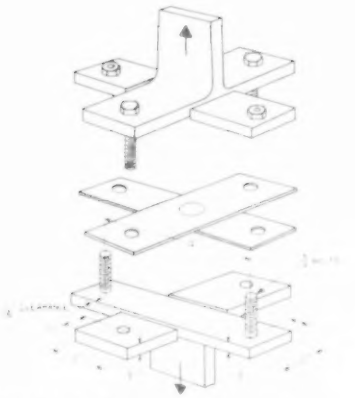


Fig. 4 Jig for cross-tension test

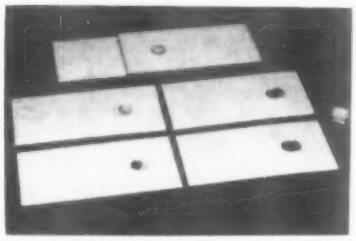


Fig. 5 Tension-shear spot-welded specimen before and after strength testing

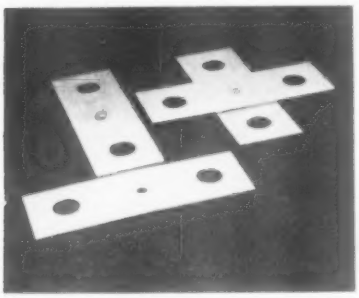


Fig. 6 Cross-tension spot-welded specimen before and after strength testing

lographic specimens indicated that the radius electrode produced welds having larger weld nuggets, better penetration, less electrode indentation and less sheet separation for the same welding parameters.

The truncated-cone electrode produced spot welds having nonuniform sheet separation and excessive electrode indentations. This was evidently due to flexing of the electrode supporting arms with the application of pressure. The subsequent slight misalignment was critical with the truncated cone but not with the radius-face electrodes.

The substitution of Class 3 for Class 2 electrodes did not significantly affect the results.

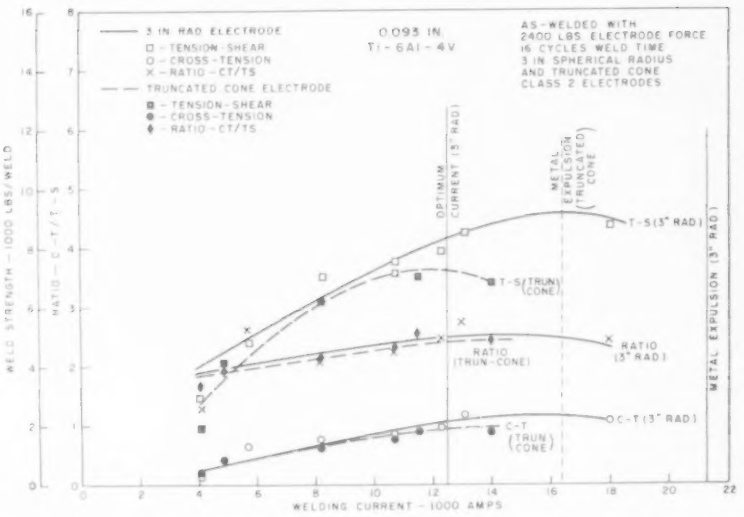


Fig. 7 Mechanical properties as functions of welding current

Table 3—Welding Variables

Run	Electrode force, lb	Weld time, cycles	Electrode geometry: Truncated cone d-Minor$^{3}/_{16}$ in., D-Major$^{3}/_{8}$ in.	Electrode geometry: 3-in. spherical radius	Current range investigated, amp
			0.035-in. sheet		
A	600	7		X	1135–10,500
B	600	7	X		1880–7560
C	750	7		X	1510–12,300
D	750	7	X		1325–7560
E	900	7		X	1420–10,850
F	900	7	X		1890–8500
			0.062-in. sheet		
A	1300	10		X	4000–16,300
B	1300	10	X		4900–11,600
C	1500	10		X	3200–19,600
D	1500	10	X		4000–10,640
			0.070-in. sheet		
A	1500	12		X	2400–21,200
B	1500	12	X		3200–12,200
C	1700	12		X	1600–22,930
D	1700	12	X		2400–12,200
			0.093-in. sheet		
A	2000	16		X	2450–16,380
B	2000	16	X		4000–16,380
C	2400	16		X	4000–21,300
D	2400	16	X		4000–16,380
E	2800	16		X	4000–21,300
F	2800	16	X		4900–16,380

Weld Time

The welding time for each Ti-6Al-4V sheet thickness spot welded was initially set at the number of cycles recommended in the Resistance Welding Manual for stainless steel. An accurate measurement of weld time was obtained with the oscillograph as was shown in Fig. 3*a*.

The initial welding cycle settings were found to produce satisfactory spot welds. The weld times ranged from 7 cycles for the 0.035-in. sheet to 16 cycles for the 0.093-in. Ti-6Al-4V sheet (Table 3).

As a further check on these initial time assumptions, a series of spot welds was made using longer welding durations than those recommended, and indications were that no advantage was thus to be gained.

Electrode Force

In an attempt to establish an optimum electrode force for each thickness, spot welds were made using the initial electrode force recommendations for stainless steel from the RWMA Manual and also forces below and above the recommended value (Table 3). Electrode

Table 4—Optimum Parameters for Spot Welding Ti-6Al-4V*

Sheet thickness, in.	*Electrode force, lb*	*Weld time cycles*	*Current range investigated, amp*	*Optimum current, amp*	*Cross-tension strengths at optimum current, lb/weld*	*Tension-shear strengths at optimum current, lb/weld*	*Ratio cross-tension strength over tension-shear strength*	*Minimum contacting overlap, in.*	*Weld diameter, in.*
0.035	600	7	2200 to 10,500	5500	600	1720	0.35	1/2	0.255
0.062	1500	10	3200 to 19,600	10,600	1000	5000	0.20	5/8	0.359
0.070	1700	12	1600 to 22,930	11,500	1850	6350	0.29	5/8	0.391
0.093	2400	16	4000 to 21,300	12,500	2100	8400	0.25	3/4	0.431

* The above specimens were welded with 1500-lb electrode force, 10 cycles weld time, 3-in. spherical radius—3/8-in. diam Class 2 copper-alloy electrodes.

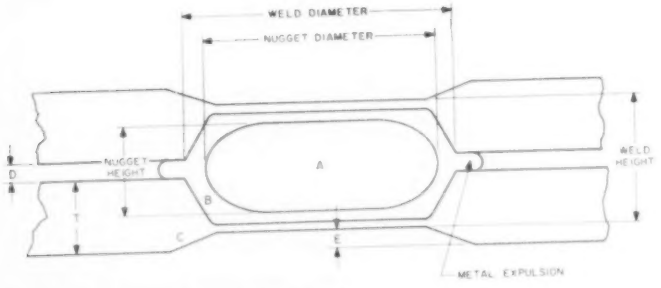


Fig. 8 Geometry of weld cross section

A, weld nugget; *B*, heat-affected zone; *C*, base metal; *D*, sheet separation; *E*, electrode indentation; *T*, sheet thickness

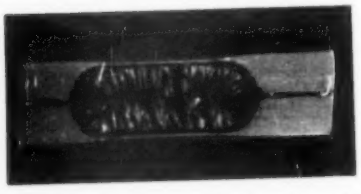


Fig. 9 Photomacrograph of weld cross section

force was measured under "no-weld" conditions with a calibrated pneumatic ram.

The recommended forces for welding stainless steel as applied to the Ti-6Al-4V alloy proved to be adequate. The electrode forces were of sufficient magnitude to assure good contact between the faying surfaces and ranged from 600 lb for the 0.035-in. material to 2800 lb for the 0.093-in. sheet.

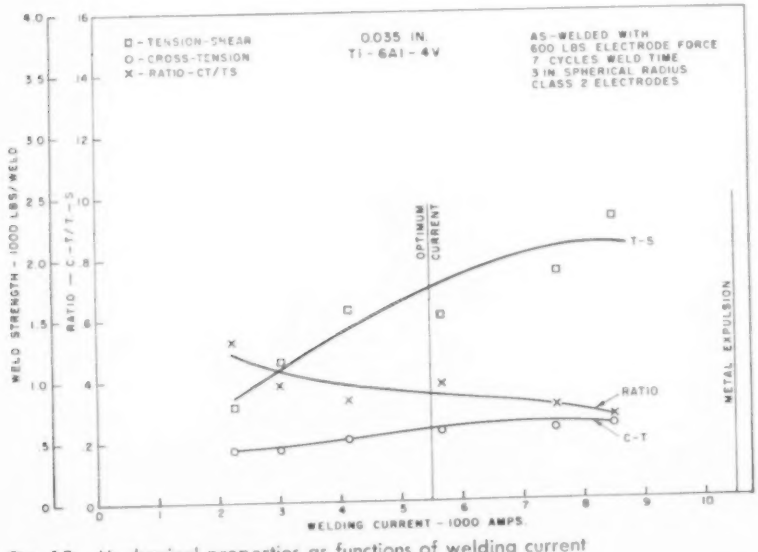


Fig. 10 Mechanical properties as functions of welding current

Forces lower than those selected as optimum were found to produce weaker welds both in tension and shear. Higher shear strengths were obtained with higher electrode forces, but the ratios of cross-tension to tension-shear were low due to low strengths of the cross tension specimens. Welding schedules using considerably higher electrode forces showed that metal expulsion occurred at lower current values than at the optimum forces for each sheet thickness. See Table 4 for the optimum electrode forces.

Squeeze and Hold Time

Throughout the investigation, squeeze and hold times were held at 60 cycles. These time periods were felt to be adequate (1) to allow electrode pressure to reach its stable value prior to application of current, and (2) to hold the specimens in place until solidification and cooling were completed.

Welding Current

For the several welding-parameter combinations, the weld current was varied from the minimum value required to weld the sheets up to the point where metal expulsion occurred. This current variation was accomplished by increasing the percent heat and recording the primary current trace on the pen oscillograph. The current amplitude value was then multiplied by the transformer constants to obtain the actual welding currents. Traces of weld current were shown in Fig. 3.

The optimum weld currents established during this period were chosen taking into consideration sheet separation, electrode indentation, weld nugget diameter, percent penetration and weld strength. The selected optimum weld currents produced satisfactory spot welds; however, in cases where some of these parameters—such as sheet separation—are not relevant, higher weld currents (up to the point of metal expulsion) may be used to obtain stronger welds. Figures 8 and 9 show a schematic drawing and an actual photomacrograph of a satisfactory spot weld. The current ranges investigated and the resulting optimum currents are shown in Table 4. Figure 10 illustrates the varia-

tion of the above parameters with changing current for the 0.035-in. sheet. The optimum current is marked on this graph. Similar plots (Figs. 7, 11 and 12) of the various parameters versus welding current were obtained for each sheet thickness, electrode pressure and electrode geometry. All of the values appearing as recommended values in Table 4 were derived from plots of these data.

Weld Strength

The weld strengths were tested in two loading systems, tension-shear and cross-tension. The ratio of the cross-tension strength to tension-shear strength is used as a measure of weld ductility.

Strengths in cross tension and tension shear, as well as the ratio between the two, at optimum welding parameters for all sheet thicknesses investigated are presented in Table 4.

The weld strength increased with increasing weld current to the point of metal expulsion at which point there was a definite decrease in weld strength. Using Fig. 11 as a typical plot (0.062-in. sheet), the tension-shear strength varied from 2400 to 5600 lb/weld and the cross-tension strengths varied from 250 to 1145 lb/weld. The weld strengths corresponding to the optimum welding parameters for the 0.062-in. material are 1000 lb/weld for the cross tension and 5000 lb/weld for the tension shear.

Sheet Separation

The amount of sheet separation was both visually observed and measured on the metallographic specimens.

It was found that the optimum welding parameters produced average sheet separation as follows:

0.035-in. sheet	0.0047 in.
0.062-in. sheet	0.0087 in.
0.070-in. sheet	0.0079 in.
0.093-in. sheet	0.0091 in.

These measurements were made at a distance from the edge of the weld, approximately equal to half the diameter of the electrode indentation. Figures 8 and 9 illustrate sheet separation on spot-weld cross sections.

If the Military Specification MIL-W-6858, Aug. 7, 1950, for spot welding austenitic steels and nickel alloys is applied in this program, the maximum acceptable sheet separation is 10% of the thickness of the sheet joined or 0.005 in., whichever is larger. The values reported for 0.062 and 0.070 in. sheet are greater than the 10% maximum acceptable value of the Military Specification. However, since there are no specifications for sheet separation for Ti-6Al-4V alloys, the data reported above may be acceptable.

Table 5 for 0.062-in. sheet shows that for low weld currents (4000 amp) the sheet separation is below the maximum acceptable percentage; but as the cur-

Table 5—Effect of Current of Weld Geometries for 0.062-in. Ti-6Al-4V Sheet*

Specimen no.	Welding current, amp	Weld diameter, in.†	Weld nugget diameter, in.†	C_T weld penetration	C_T electrode indentation†	Sheet separation, in.†
3	4,090	0.223	0.008	73.2	1.0	0.0035
5	6,550	0.226	0.205	72.6	1.0	0.0071
7	8,190	0.316	0.271	83.6	3.0	0.0082
9	9,820	0.324	0.295	81.4	2.6	0.0078
11	10,600	0.359	0.331	87.3	3.1	0.0087
13	13,100	0.368	0.332	78.4	4.7	0.0078
15	16,380	0.398	0.372	84.0	5.5	0.0084
17	19,600	0.440	0.403	100.0	13.5	0.0044

* The above specimens were welded with 1500-lb electrode force, 10 cycles weld time, 3-in. spherical radius —⅜-in. diam class 2 copper-alloy electrodes.

† See Fig. 8.

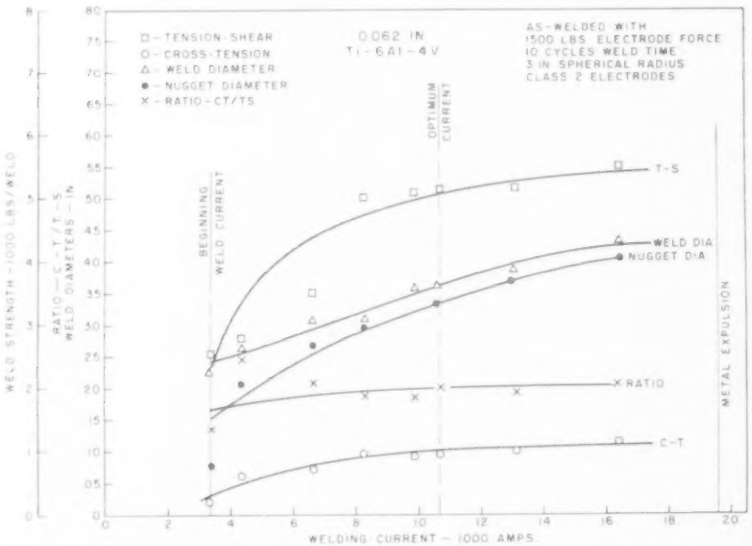


Fig. 11 Mechanical properties and weld geometry as functions of welding current

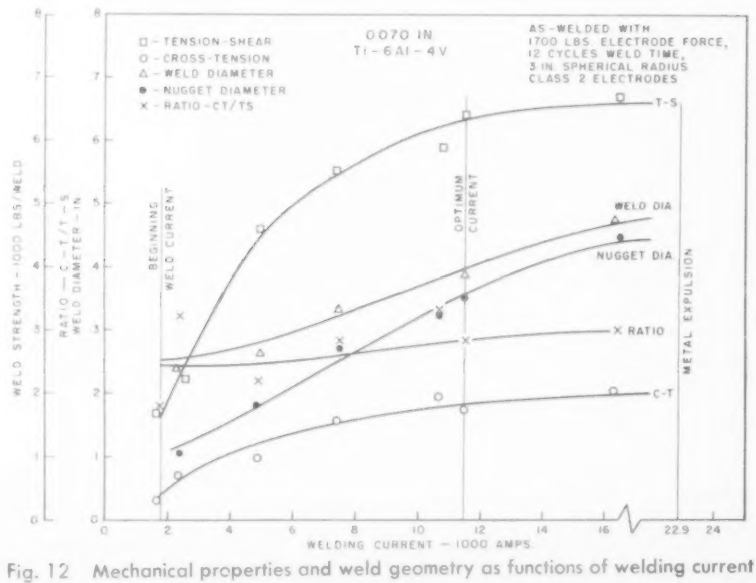
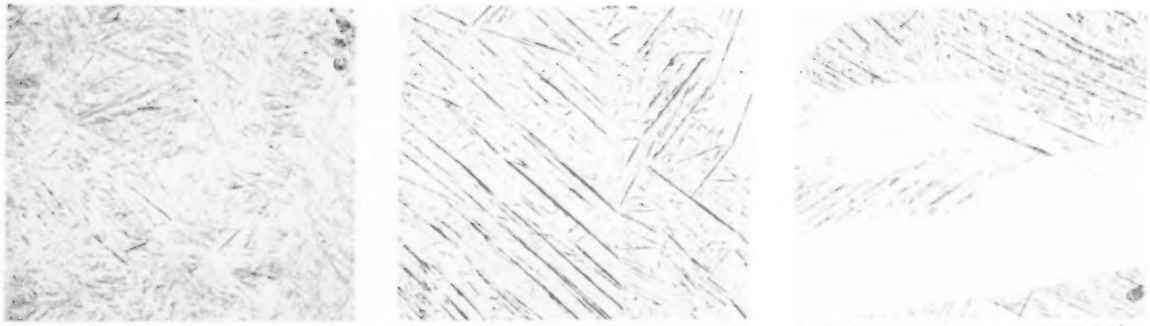


Fig. 12 Mechanical properties and weld geometry as functions of welding current



(a) As-welded, no postweld heat treatment

(b) Furnace postweld heat treatment in air for 10 min at 1500° F, water quenched

c) Torch postweld heat treatment 1400° F/10 sec

Fig. 13 Microstructure of Ti-6Al-4V spot welds as-welded and with heat treatments

rent is increased, the sheet separation increases and remains fairly constant up to the point of metal expulsion (19,600 amp), at which time the sheet separation decreases. Therefore, users of the data who are interested in following the MIL-W-6858 Specification in regard to sheet separation would find that, for low current values, the weld strengths are also low.

Weld Geometry and Sheet Appearance

Metallographic examination was utilized for determining electrode indentation and weld geometry. Figure 8 shows the sections of the spot weld that were measured and used in the various calculations.

Table 4 shows the optimum weld diameters for the four thicknesses spot welded during the project. It can be seen in Fig. 11 that, with an increase in weld current, the weld nugget diameter and the over-all weld diameter approach each other.

The values for percent weld penetration and percent electrode indentation are reported for the 0.062-in. sheet in Table 5. For the optimum weld of this thickness, the percent penetration and electrode indentation are 87% and 3%, respectively. The Military Specification MIL-W-6858 mentioned previously states that these percentages are not acceptable if they exceed 90 and 10%, respectively.

Analysis of the data indicated that, for the four sheet thicknesses spot welded at optimum machine settings, the average values were 82% for weld penetration and 3% for electrode indentation.

Significance of the Ratio of Cross-Tension to Tension-Shear Strengths

Speaking generally about the mechanical properties of materials, it may be considered that two fundamental properties determine how a structure will react to load; these are strength and ductility. Thus, glass is very strong if loaded in the absence of stress gradients or concentrations, as in the uniaxial loading of glass filaments that have had the defects removed which are usually present at the surface. If stress gradients or concentrations are present, it is essential that a material have some inherent ductility to distribute and relieve these stresses.

A tension-shear test on a spot-welded specimen does give some indication of ductility since stress gradients and concentrations are set up by the nonaxiality of the specimen, the attendant bending stresses, and the stress concentration at the end of the spot weld. A cross-tension specimen undergoes even more severe loading and therefore is a still better evaluation of ductility. It should be kept in mind, however, that spot welds in service are practically never subjected to this type of loading. Presumably, if extremely brittle zones exist in the region of a spot weld, the specimen will have low resistance to this type of loading, cross-tension strength will be low, and the commonly used ratio of cross tension to tension shear will be low.

It can be seen from Table 4 that the ratios obtained in the investigation ranged from 0.20 to 0.35. This is considerably lower than the ratios obtained for aluminum, but the individual strengths are higher than for aluminum. Failure was by button pull-out at the interface between base metal and heat-affected zone, and not through the nugget. Although it would be of advantage to increase the ratio (without decreasing the tension-shear strength), it is felt that the properties of the spot welds obtained on this program are quite adequate.

Postweld Heat Treatments

The heat developed during spot welding produces a microstructure in the weld nugget that is martensitic in appearance. Figure 13*a* shows a typical Ti-6Al-4V as-welded microstructure. In an attempt to obtain an annealed weld nugget with an equiaxed alpha structure, and higher ratios, three types of post-weld heat treatments were investigated.

Furnace Treatment. The tension-shear and cross-tension specimens for

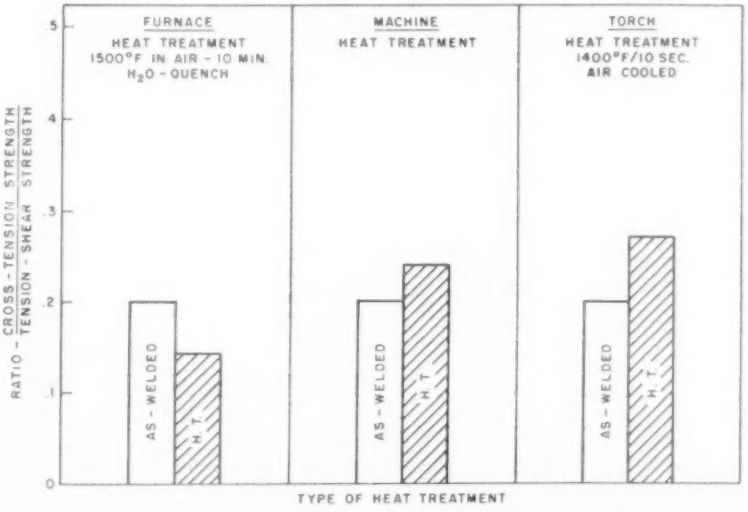


Fig. 14 The effects of heat treatments on ratios of cross-tension strength to tension-shear strength of the as-welded 0.062-in. Ti-6Al-4V sheet

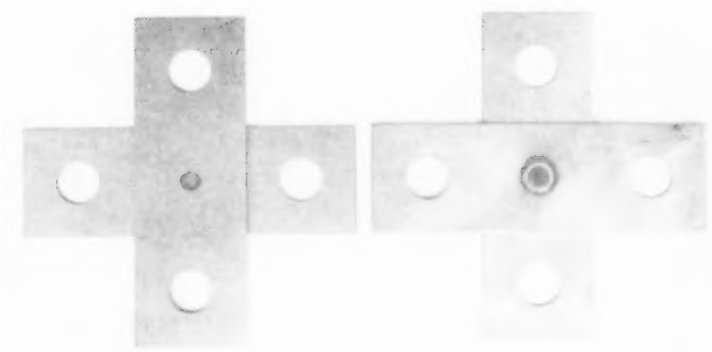


Fig. 15 Spot-welded cross-tension specimens. Specimen at left is as-welded; the one at the right was torch heat treated. Note concentric temper heat rings

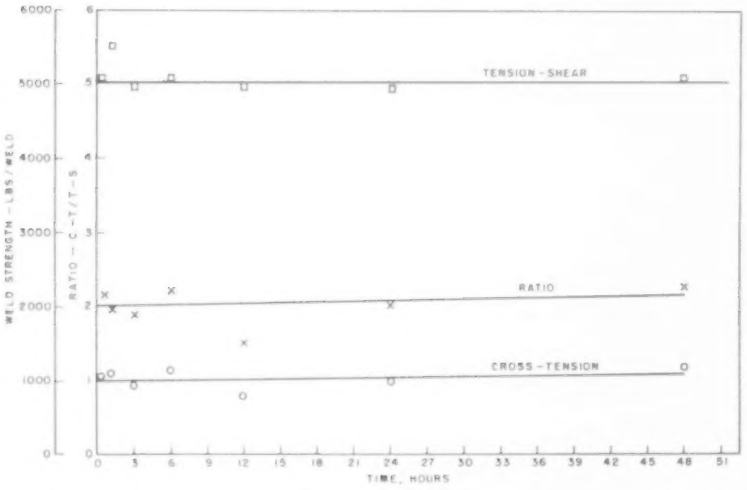


Fig. 16 Room-temperature mechanical properties as influenced by heating to 700° F in air for various times (0.062 in. Ti-6Al-4V)

the 0.062-in. sheet were welded with percent heats varying from the point of minimum current required for a weld up to the point of metal expulsion. These specimens were placed in a furnace in air and brought up to 1500° F (approximately 10 min required) and water quenched. A pickling treatment (30% HNO_3, 3% HF, 67% H_2O at 150° F) was employed to remove possible contamination from the spot, and the specimens were then tested for strength.

Figure 14 shows that this type of heat treatment proved to be an unsatisfactory means of improving the cross-tension strength to tension-shear strength ratio. The ratios obtained using optimum welding parameters were approximately 0.139. However, as-welded specimens under the same conditions as above but with no furnace treatment had ratios of 0.20. Possibly contamination by air in the furnace caused this deleterious effect. Figures 13*a* and 13*b* show microstructures of the as-welded and the furnace-treated spot welds. These indicate no structure change.

Post-Weld Heat Treatment in the Welding Machine. Some effort was spent in performing heat treatments in the welding machine. With the available controls it was possible to investigate a variety of heat treatments, examples of which appear in Figs. 3*a*, 3*b* and 3*c*. Some of the heat treatments incorporated up-and-down slope, quench time and pulsation current.

It was observed that this heat treatment of a series of spot welds did improve the ratio slightly. The strengths of the cross-tension specimens were increased while the tension-shear strengths were not affected appreciably. Figure 14 indicates that with this heat treatment the ratio was increased from 0.20 to 0.24 by combining up-and-down slope, quench time and pulsation current. The total time required for producing a spot weld and heat treating it was approximately 1.5 sec. From this standpoint, the operation is an extremely practical one, and it is believed that various other combinations of settings would increase the ratios to even greater values. It should be emphasized that this phase of the program was necessarily of a cursory nature. The machine possibilities are almost infinite, and additional investigation shows promise of obtaining much greater improvements in properties.

The microstructures for this type of heat treatment are similar to those for the torch heat treatment as shown in Fig. 13*c*. However, it was observed that the heat-affected zone of the machine heat-treated specimens was not as enlarged as the one for the torch treatment.

Torch Heat Treatment. This heat treatment was accomplished by a reducing flame from an oxyacetylene heating torch. The specimens were heated to 1400° F for approximately 10 sec. A temperature-indicating crayon and observation of the heat color were the rather crude methods used to check the 1400° F temperature. The flame was concentrated on the center of the spot weld so as to enlarge the heat-affected zone surrounding the weld nugget (Fig. 15).

The results of this type of post-weld heat treatment have shown that the ratio was improved to a value higher than produced by any other heat treatment performed during the investiga-

Table 6—Effect of Elevated Temperature on Subsequent Room-Temperature Strength

	(Duplicate Specimens) Weld Strength, lb/weld			
Type of test	*Cross-tension*	*Tension-shear*	*Ratio:*	*Cross-tension / Tension-shear*
Room temperature, as-welded	805	5140		0.15 avg.
	750	5100		
Thermal stability (750° F for 160 hr)*	975	4320		0.23 avg.
	975	4310		
Stress stability (750° F for 200 hr under a load of 1500 lb)*	...	4860		
	...	4700		

* Strength at room temperature following the stability test.

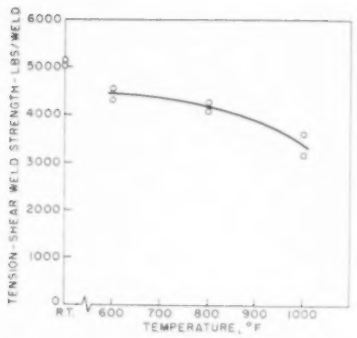


Fig. 17 Elevated-temperature tension-shear strength of spot welds (0.062 in. Ti-6Al-4V)

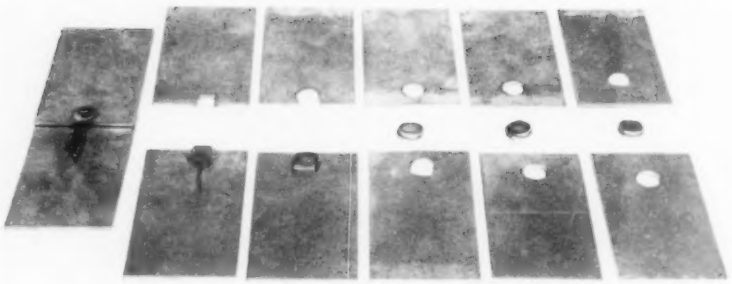


Fig. 18 The effects of minimum contacting overlap on the types of resulting failure for tension-shear specimens

The specimen at the left is 0.070-in. sheet with overlap of $\frac{3}{4}$ in. Overlap distances for the other tested 0.062-in. specimens from left to right are: $\frac{3}{16}$, $\frac{1}{2}$, $\frac{3}{8}$, 1 and $1\frac{1}{2}$ in. A decrease in overlap changes failure from button-pull out to end tearing of sheet

tion, as shown in Fig. 14. For the 0.062-in. sheet, average value for tension-shear strength of the as-welded specimens was 5000 lb/weld; the average cross-tension strength of the as-welded specimens was 1000 lb/weld. The data on the torch treatment gave an average tension-shear strength of 4810 lb/weld and an average cross-tension strength of 1320 lb/weld. The ratio was increased from 0.20 to 0.27.

Figures 13*a*, 13*b* and 13*c* show microstructures for the as-welded, the furnace-treated and the torch-treated spot welds respectively. The heat-affected zones on the torch heat-treated welds were extended farther into the base metal than with the other treatments, even though the photomicrographs do not show this.

Effects of Elevated Temperatures on Weld Properties

Several types of evaluations of the effects of elevated temperatures on weld properties were made on 0.062-in. sheet. Both tension-shear and cross-tension specimens were welded using the following optimum parameters: 1500-lb electrode force, 10 cycles weld time, 10,600 amp, 3-in. spherical radius —$\frac{3}{8}$-in. diam Class 2 copper electrodes.

One series of specimens was heated in air at 700° F for times ranging from $\frac{1}{2}$ to 48 hr, then air-cooled. The effects of this thermal-stability evaluation on subsequent room-temperature strengths are illustrated in Fig. 16. For the time intervals investigated, the strengths were relatively unchanged.

Another series of tests was run involving both thermal stability (elevated temperature under no load) and stress stability (elevated temperature under load). In both cases, the strength of the weld was determined at room temperature after the exposure to elevated temperature. Duplicate specimens were run. The results are presented in Table 6. It can be seen that heating at 750° F for 100 hr under no load increased the cross-tension strength and decreased the tension-shear strength. The ratio of cross-tension strength to tension-shear strength increased, indicating a general increase in ductility with a decrease in strength. Exposure to air at 750° F for 200 hr under a load of 1500 lb lowered the subsequent room-temperature tension-shear strength some 325 lb, less than the decrease obtained in the thermal-stability tests.

The short-time elevated-temperature tension-shear strength of spot welds is presented in Fig. 17. The strength decreased from a room-temperature value of about 5100 to about 3400 lb at 1000° F.

Minimum Contacting Overlap

The objective of this phase of the program was to determine what minimum overlap distance would change the shear strength and type of failure for the shear specimens. The overlap distance was decreased from the recommended length as stated by the RWMA for standard tension-shear specimens, down to the distance where the small overlap caused metal expulsion. The 0.062-in. material was used for this test, and the optimum welding parameters were held constant.

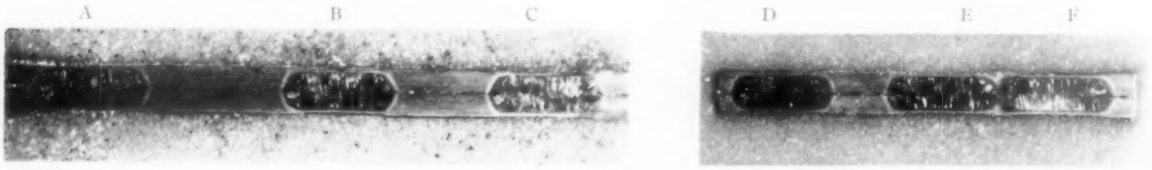
The values that appear in Table 4 are based on the type of failure. That is, for these lengths the failures were of plug pull-out type and not of the end tearing of the sheet as was the situation for the smaller overlap distances (Fig. 18). For each thickness the overlap distances investigated were $1\frac{1}{2}$, 1, $\frac{3}{4}$, $\frac{1}{2}$ and $\frac{1}{4}$ in.

With the 0.062-in. sheet as a typical thickness, metal expulsion occurred when the overlap was decreased to $\frac{1}{4}$ in. and end tearing of the sheet during the tension-shear strength testing occurred when the end contact distance was $\frac{1}{2}$ in. The values shown in Table 4 have been increased to include a factor of safety.

Shunting Current Effects and Minimum Spot Spacing

A study of the minimum permissible distance between spot welds was made. When the spot welds are placed too close together, in most materials, a portion of the current required for the second weld is shunted through the preceding weld. The resulting weld may be weak because of low current.

The distance between welds was decreased from $1\frac{1}{4}$ to $\frac{3}{4}$ in. in increments



(a) Distance from *A* to *B* = $\frac{3}{4}$ in. Distance from *B* to *C* = $\frac{3}{4}$ in.

(b) Distance from *D* to *E* = $\frac{1}{2}$ in. Distance from *E* to *F* = $\frac{3}{4}$ in.

Fig. 19 The effect of spot spacing on weld geometry

of $\frac{1}{4}$ in. The spot welds were made using the 3-in. spherical radius electrodes. When the distance between spots was $\frac{1}{2}$ and $\frac{3}{8}$ in. there was some indication from visual observation of the outside surface that the electrode indentations were elliptical in shape. The nugget size of the second weld was not appreciably reduced by shunting current losses until the spacing was almost so small as to obtain spot overlap. The high electrical resistance of titanium prevents excessive shunting (Fig. 19).

Summary and Conclusions

From an analysis of the data obtained during a program of spot welding Ti-6Al-4V alloy, the following conclusions can be made:

Welding Parameters

The electrical and thermal properties of the titanium alloy are similar to those of stainless steel. The validity of the assumed similarity in spot-welding behavior was substantiated by the fact that optimum welding parameters for Ti-6Al-4V were found to be similar to the recommended machine settings for welding like thicknesses of stainless steel. Table 4 shows the recommended parameters.

Spot-Weld Quality

The 3-in. spherical radius $\frac{1}{4}$-in. diam Class 2 copper-alloy electrodes produced better spot welds than truncated-cone electrodes.

Metallographic examination of weld geometry and the outside appearance of the material after welding indicate that the optimum machine settings produce sound spot welds.

The spot strengths of the Ti-6Al-4V alloy exceed the minimum acceptable strengths for comparable thicknesses of stainless steel. However, the ratios of cross-tension to tension-shear for Ti-6Al-4V, as for other titanium alloys, are lower than the ratios for stainless steel. Perhaps the ratios for titanium alloys may never be as high as the ones for stainless steels and other materials, but it is believed that the existing Ti-6Al-4V ratios can be improved without significant loss in shear strengths.

Minimum contacting overlaps and spot spacings as determined by weld strengths were found to be comparable to the values for equal gages of stainless steel.

PostWeld Heat Treatments

The limited amount of time devoted during the period of research to the investigation of post-weld heat treatments indicated that the ratio could be improved.

The ratio of cross-tension strength to tension-shear strength of spot-weld specimens is a measure of the weld ductility. Therefore, to the users of the data an improvement of this ratio is important.

The furnace and torch post-weld heat treatments were of academic importance in that they helped to indicate what times and temperatures were necessary to produce conditions in the weld structures required for increased ratios. However, from the practical viewpoint, heat treatments in the machine are feasible, reproducible and easier to accomplish.

Effects of Elevated Service Temperature

The tension-shear strength of spot welds decreases with increasing temperature, from 5100 lb/spot at room temperature, to 4400 lb/spot at 600° F, to 3300 lb/spot at 1000° F.

Exposure to air at 700° F under no load for times up to 48 hr did not appreciably effect weld strength. Exposure at 750° F for 160 hr reduced the tension-shear strength and increased the cross-tension strength at room temperature.

Exposure to air at 750° F for 200 hr under a load of 1500 lb reduced the room-temperature tension-shear strength from about 5120 lb/weld to 4780 lb/weld.

Acknowledgments

The authors wish to acknowledge the sponsorship of this project by the Titanium Metals Corporation of America and their permission to publish this paper.

EFFECT OF FABRICATED EDGE CONDITIONS ON BRITTLE FRACTURE OF STRUCTURAL STEELS

BY L. A. HARRIS AND N. M. NEWMARK

Static tensile tests were conducted on specimens of a rimmed steel and a semikilled steel meeting ASTM A-7 requirements, a structural silicon steel (ASTM A-94) and a low-alloy high-tensile steel (ASTM A-242). The fabricated edge conditions used included machined edges, sheared edges, flame-cut edges and, in some cases, flame-cut edges subsequently flame softened. The flame-cut edges were prepared by both manual and guided flame-cutting techniques.

It was concluded from the tests that for all the steels tested the strength and ductility of the machined edges were good. For all except the silicon steel, the strength and ductility of the guided flame-cut edges were also good. However, with the manual flame-cutting procedure, there was in some cases serious impairment of the physical properties. Even guided flame cutting impaired the properties of the silicon steel, but ductility and strength appeared to be restored by subsequent, appropriate flame softening of the edge.

The sheared edge impaired the ductility of all of the steels tested. The greatest loss in ductility was caused in the semikilled steel where the maximum strength also was reduced, in some instances falling as low as the yield strength. The harmful effect of the sheared edge on the ductility was apparently alleviated by a subsequent flame-softening treatment. The strength and ductility apparently were increased, but it is not known whether equally beneficial results would be obtained with larger members because of the residual tensile stresses introduced by such flame softening.

Only under the most damaging edge conditions was the strength at a brittle fracture as low as the yield point. With the better methods of edge preparation, the strength was considerably above the yield point and approached the usual ultimate strength of the material.

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Abstract of a report of an investigation conducted by the Department of Civil Engineering, University of Illinois, in cooperation with Committee 15—Iron and Steel Structures, American Railway Engineering Assn.

SEAM WELDING GALVANIZED STEEL

Report describes the changes in welding variables required to produce acceptable seam welds when using zinc-coated weldments, and shows the effect of zinc upon the physical and metallurgical characteristics of the weld metal

BY W. J. ALLEN AND M. L. BEGEMAN

Introduction

This report is the first of two pertaining to the effect of zinc coatings upon the variables encountered in the resistance seam welding of coated-steel sheet. Because zinc has long been used successfully as a protective coating on steel to prevent rapid corrosive deterioration, welding procedures should be established so that coated steel can be fabricated while still retaining corrosive resisting properties. This report describes the changes in welding variables required to produce acceptable seam welds when using zinc-coated weldments, and shows the effect of zinc upon the physical and metallurgical characteristics of the weld metal.

Although zinc coating is an excellent corrosion resistant for sheet steel, certain problems arise when galvanized steel is fabricated by resistance welding. The zinc coating may be boiled away, extruded from beneath the electrodes, alloyed with steel or any combination of these during welding. Some of the zinc at the weldment interface may be trapped in the weld zone and appear in the weld nugget as an alloy or oxide. Also, some phases of iron-zinc alloys are found to be hard and brittle even though both materials are originally quite ductile. The coating zinc has a greater affinity for the alloyed copper electrodes than for the weldment base metal, and this not only reduces the protection of the fabricated joint, but also causes excessive electrode buildup. Since the above conditions are not present in the resistance welding of uncoated steel, the machine settings for such steel cannot be expected to give optimum welds in zinc-coated weldments. In selecting the machine settings for zinc-coated steel, one should consider (1) the degree of effective coating present after welding, (2) the physical and metallurgical characteristics of the weld metal due to the influence of the zinc and (3) the condition of the electrodes during welding.

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Paper to be presented at 1958 AWS Annual Spring Meeting to be held in St. Louis, Mo., April 14th to 18th.

Material and Equipment

The material used throughout this investigation was 22-gage, hot-dipped, galvanized sheet steel. The average chemical analysis of the base metal was: carbon, 0.06%; manganese 0.25-0.26%; phosphorus, 0.009%; sulfur, 0.023-0.024%; copper, 0.023%; tin, 0.005%.

The average base-metal thickness was 0.032 in. and the coating thickness on each surface was approximately 0.0017 in. All test welds for metallurgical examination were made on the center of strips 1 in. wide.

A circular seam welder of 250-kva capacity was used in connection with an electronic control unit to produce all welds.* Electrodes were of the RWMA Class 2 alloy, 10 in. in diameter and 1½ in. thick, with edges beveled at 15 deg to accommodate the knurled drive wheels.† The electrode face used was ¼ in. in width. The welding current was measured by means of a current transformer, pointer stop ammeter circuit. The electrode force was measured with a direct-reading electrode force gage and weld porosity determined by using a 150-kv industrial X-ray machine.

Procedure

All testpieces were welded in the as-received condition. It was assumed that any surface treatment such as wire brushing or washing with a solvent would tend to alter the character of the zinc coating by distorting the spangles and removing any oxide films.

* The seam welder and electronic control were furnished by RWMA.

† Electrodes were furnished by P. R. Mallory and Co.

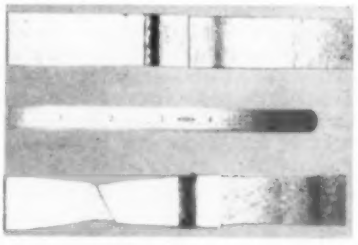

Fig. 1 Types of failure encountered with tensile test specimens

First, using the recommended practices set forth by the RWMA Handbook for uncoated material, a number of coated-weldment tests were made and evaluated metallurgically. All tests were made at 60 ipm. These data were then compared with uncoated-weldment results and with the required standards. This phase established the fact that coated weldments did alter the combination of machine settings necessary for welds of consistent high quality.

The prime welding variables to be investigated were welding current, current timing and electrode force. In the selection of satisfactory welding variable ranges, a welding speed and electrode force were first assumed and the cyclic welding combinations and welding current were then varied until the most effective combination was established. Force and current variations were then made using the most likely cyclic combinations. From these data the most effective on-off setting was determined. These test welds were evaluated by X-ray, metallurgical and physical tests.

In order to determine the strengths of welds made under different conditions, specimens 1 in. wide were cut

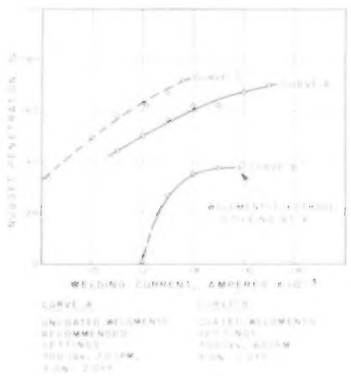

Fig. 2 Nugget penetration of galvanized and uncoated weldments (22 gage)

from larger welded coupons and tested in a tensile machine. The principal types of failure experienced are shown in Fig. 1. The specimen at the bottom demonstrates failure in the base metal which indicates a physically acceptable weld, while the specimen at the top failed in the weld. Occasional pillow tests were made to check the soundness and uniformity of the welds.

Finally the welds, using the most satisfactory machine settings, were tested for corrosion resistance. These tests were based on the protection offered in the weld area as compared to that of unwelded stock. The corrosion protection was qualitatively evaluated by immersing the test specimen in a 0.01 molar solution of sodium sulfate for approximately one week. Each specimen was 1 in. wide, 4 in. long and required 500 ml of solution. Other specimens were placed in a humidity chamber held at a constant temperature for longer periods of time.

Results

Past experience has indicated that coated weldments increase welding current requirements. The data and discussions which follow show that the introduction of an alloyable material between the weldments of a conventional resistance-welding circuit creates a situation which is not only different from the welding of uncoated material, but more complex in nature.

The basis of weld evaluation in this investigation was percent nugget penetration which is defined as the ratio of nugget thickness to the final joint thickness at the center of the heat-affected zone. The existence of a well-formed resistance weld nugget of measurable thickness is known to preclude any tensile failure in the weld zone. The acceptable penetration range set by the Resistance Welder Manufacturers' Association is from 30 to 70%. Tensile tests, porosity and corrosion resistance checks supplement the basic evaluation.

To establish the fact that zinc coatings on the surfaces of weldments required appreciable changes in the welding variables, a number of test welds were made using the schedule suggested for similar, but uncoated, steel of the same thickness. The result of varying the welding-current settings while holding the other variables constant for uncoated steel is illustrated by Curve A in Fig. 2. A similar variation for zinc-coated weldments, with slightly lower speed is shown by Curve B. A comparison of the curves reveals that (1) the maximum nugget penetration of Curve A is much greater than that of Curve B, and (2) the current range from zero to maximum penetration for coated weldments is much shorter. Curve C is produced by holding all variables the same as in Curve A but the speed was reduced to 60 ipm, the same speed as used in Curve B. The resulting curve is similar in every respect to Curve A, but is moved to the left because of the lower current requirements at the reduced speed. The lower maximum penetration obtained with coated weldments indicates that the amounts of heat generated at the weldment's outside surfaces are no longer small compared with that at the interface. For the condition where all contact resistances are nearly equal, the weldment surface heats nearly equal that at the interface. This results in surface burning, low penetration and excessive electrode pickup. This condition develops because of the ability of zinc to alloy with copper. The welding electrodes, made of a forged copper alloy, pick up some of the zinc coating which tends to alloy with the electrode material under the heat of welding. The alloying effect apparently reaches an operating mean where the edge of the electrode is rich in

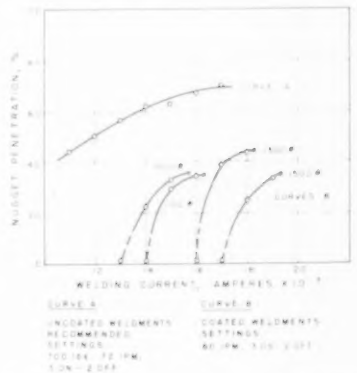

Fig. 3 Nugget penetration of galvanized weldments (22 gage) for increased electrode forces

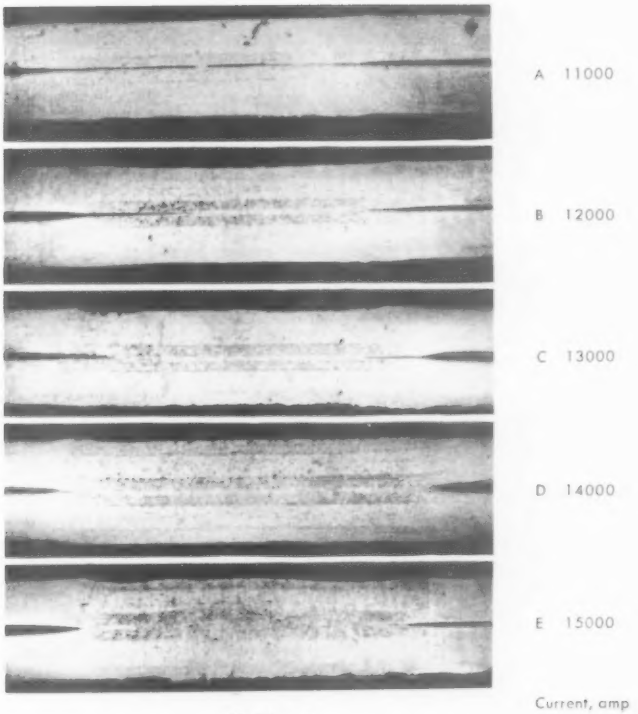

Fig. 4 Macrographs of weld development using interrupted current. Electrode force 700 lb, welding speed 60 ipm, current pattern 3 "on" and 2 "off", and 22-gage galvanized low-carbon steel

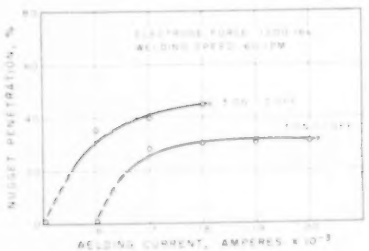

Fig. 5 Effect of reducing "off" time on galvanized weldment (22 gage) penetration for three-cycle "on" time

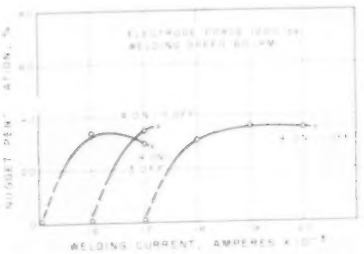

Fig. 6 Effect of reducing "off" time on galvanized weldment (22 gage) penetration for four-cycle "on" time

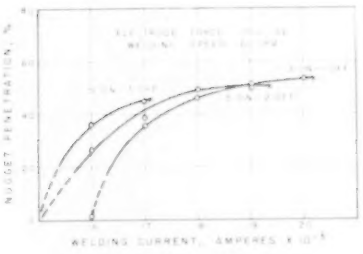

Fig. 7 Effect of reducing "off" time on galvanized weldment (22 gage) penetration for five-cycle "on" time

zinc. Zinc coating of the electrode edge follows. While electrodes in this condition result in surface and interface contact resistances which are nearly equal, an improved resistance balance may be obtained by some form of electrode dressing.

Alloying and zinc buildup are also responsible for the short current range of acceptable penetrations. Maximum penetration is stopped short due to premature electrode sticking. Note that the penetration difficulties shown may be attributed principally to the zinc coating which is in contact with the electrodes and that the coating material at the interface seems to have little direct effect on penetration.

Although there was little indication that an improvement in penetration characteristics could be expected by using a different electrode force, a series of welds at various electrode forces was made and evaluated. The resulting curves are shown in Fig. 3 along with Curve A of the previous figure. The penetration ranges in each case are still short and maximum penetration considerably below that of the uncoated-weldment curve. A marked improvement in penetration was obtained at electrode forces of around twelve and thirteen hundred pounds. At these pressures, under the conditions previously mentioned, there could be a mechanical rupturing of the zinc-oxide films on the electrode faces, and this, with the increased tendency to squeeze the zinc out of the weld area, would improve the resistance pattern of the welding circuit. There is no formal data, however, on which this may be based.

Study of Current Interruption

The current-interruption pattern of a welding schedule not only determines the degree of nugget overlap or spacing, but also provides the best method of altering the heat-affected zones. Once set into the welder, the pattern is repeated without alteration during welding operations.

The test welds of Figs. 2 and 3 were made using the recommended pattern for uncoated material of 3 "on" cycles and 2 "off" cycles. The macrographs of Fig. 4 (Curve B of Fig. 2) show the heat zones' development as the current is increased with this pattern. At the lowest current setting, little heat is generated at any point in the weld area but, as the current is increased, the first heat zone appears at the joint line (Weld B). At the next current increase, the interface heat zone is larger and the trapped zinc coating begins to alloy with the base metal (Weld C). This current has developed surface heat zones and there are some evidences of alloying. The same appears to be true in both Weld D and Weld E, while the penetration increases slightly.

It was believed that by altering the current-interruption pattern, the heat generated at the interface could be increased without appreciably raising the surface heats. Nugget penetration versus current curves were developed for several current-interruption patterns by increasing the welding current (other variables held constant) until electrode sticking occurred. Figures 5, 6 and 7 show that as the cool times are reduced the penetration ranges are expanded. In Fig. 5, a reduction of "off" time causes a decrease in maximum penetration but indicates that welding is possible over a wider range. The decrease in penetration may be due to the increased current shunting effect as the nuggets become closed or overlapped. This effect is reduced as the "on" time is increased (Figs. 6 and 7). The significant factor shown from these curves is the improved character of the curves as the "on" time is increased and the "off" time is decreased. Figure 8 shows a composite of the one cycle "off" curves from the three previous plots. The increased penetration with increased "on" time is apparent, and this, with the improved character of the low "off" time curves, indicates a trend toward continuous current. A similar trend occurs as the cooling or "off" time is decreased for any given "on" time. The curves in Figs. 5, 6 and 7 show an increased tendency toward surface arcing and flashing and electrode sticking as the "off" time is increased. This

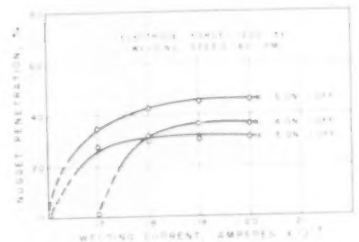

Fig. 8 Effect of increased "on" time for galvanized weldments (22 gage)

can be expected with low-melting temperature coatings when the cool time is sufficiently long to permit solidification of the coating material under electrode pressure.

A plot of the results obtained using continuous current is shown in Fig. 9 below the uncoated material reference plot. Although the maximum penetration still falls short, the penetration range is quite good.

Coated-Weldment Effects on Current Requirements

The pure mechanism of resistance welding is not altered by the introduction of a coating material in the weld zone. A series of welds is shown in Fig. 10 in which the welding current was increased in 1000-amp steps while the

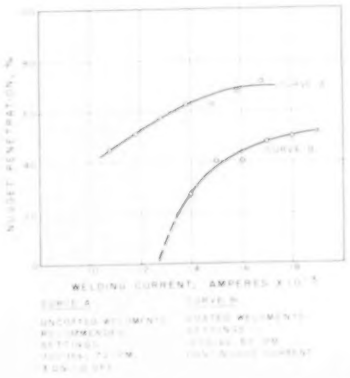

Fig. 9 Penetration range of galvanized weldments (22 gage) using continuous current

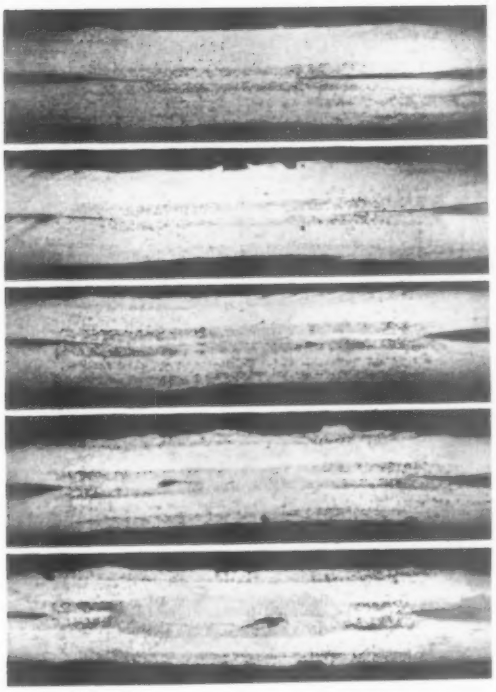

Fig. 10 Macrographs showing effect of current variations on galvanized weldments. Electrode force 1200 lb, welding speed 60 ipm, current pattern 3 "on" and 2 "off", and 22-gage weldments

other variables were held constant. Weld A is typical of a low heat where only the coating material at the interface is fused. Some alloying of the zinc is evident in Weld B at the interface, and a characteristic columnar grain growth, associated with weld nuggets, has begun across the joint line. The nugget has formed in Weld C and further current increases result in greater nugget width rather than in penetration. The heat effects and the alloyed coating material at the weld surfaces are shown in Welds D and E. Weld E shows the closest resemblance to a weld nugget in uncoated material, but there was considerable electrode sticking at that current.

Once the nugget has been formed in uncoated weldments, penetration increases rapidly as the welding current increases. Upon introducing zinc into the weld area, a number of changes occur which may be seen in Fig. 11. The penetration curve has a gradual slope over the range and the point at which the nugget formation first takes place is not readily determined. The macrograph for 15,000 amp shows traces of the joint line in the nugget formation, but tensile tests indicate a maximum joint efficiency. This condition closely resembles the solid-phase bonding frequently encountered when there is insufficient heat to form a nugget. With these particular weldments, the characteristic nugget structure borders the alloyed strip along the joint line, and grain growth in the strip joins the two structures. Although the tensile tests indicate maximum efficiency, the homogeneity of the structure may be questioned. At 16,000 amp, the nugget structures are joined at the center and the current increases from this point cause more nugget growth along the joint line than perpendicular to it.

By coating weldments with zinc, higher currents are required for a given welding situation. During welding, a portion of the zinc is squeezed from the interface by the electrode force, and a considerable amount is lost by vaporization before the base metal is melted. The vaporization carries heat from the weld areas and alters the welding-circuit contact resistance at the weldment interface. The heat losses and uncontrolled change of variables are the bases of higher current requirements related to the welding of zinc-coated material.

Coated Weldment Effects on Electrode Force Requirements

The force requirements for any resistance-welding situation are directly related to the contact-resistance magnitudes of the electrodes and weldments, and may be expected to show similar results upon variation. Since increased electrode force reduces the contact resistance, a plot of nugget penetration versus increasing electrode force should show a smooth decreasing curve. Contrary to this statement, it appears that some combination of mechanisms occurs during the welding process of coated materials which results in points of discontinuity on the curve. This same phenomenon was observed in both 18 and 20 gage galvanized sheet, but was not quite as pronounced as shown in the curve in Fig. 12. Variations in the curves can be partially explained by the fact that it is difficult to hold a true force value on the machine with the variation as great as fifty pounds either way.

Referring again to the curve in Fig. 12, it is possible that the well defined increase in penetration at 1200 lb indicates a gradual failure of the surface films. The dashed portion of the curve represents an estimated penetration that would result if the film were ruptured at the lower forces, although there are no experimental data to support this theory. Uncoated weldments have much lighter films and the point of their mechanical failure results in such a small penetration increase that it is passed over as an acceptable variation from the mean. The surface films on zinc have a larger effective resistance, and, when ruptured at the points of electrode contact, permit a greater heat generation at the weldment interface.

Metallurgical Analysis

The zinc coating and its related surface film disturb the welding-circuit balance and increase the difficulties in fabrication. The low melting temperature of zinc also has its effect on the resulting structure of the weld. Since zinc not only melts but also boils at temperatures below the fusion temperature of steel, certain weld defects may be directly related to the presence of the zinc coating.

The amount of alloying that takes place between the coating and base metals is dependent on several factors, the most obvious being the volume of zinc present in the weld area, a factor affected by some variables of the welding process. The diffusion of metals is related also to time and temperature. All base metal in the heat-affected zone may be altered by the zinc coating if the volume of zinc is relatively large, the temperature high (but not high enough to boil off the zinc) and the heat time sufficiently long.

The interrelation of time and temperature may be observed by examining the material prior to welding or in the

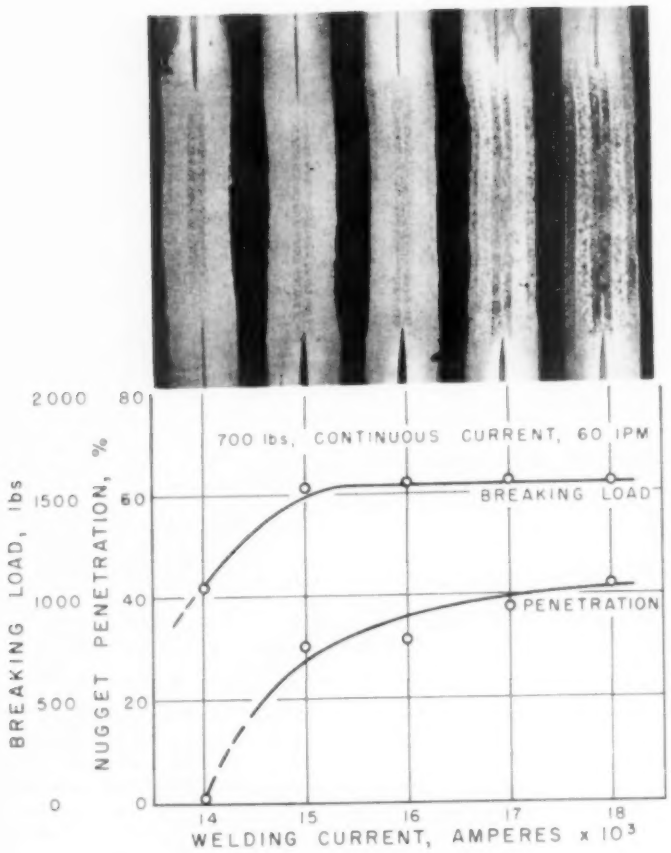

Fig. 11 Relation of macrostructure and strength of galvanized weldment welds

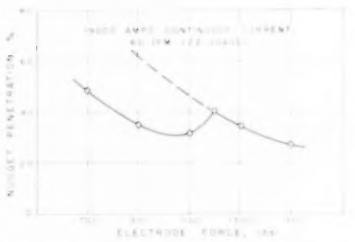

Fig. 12 Effect of electrode force on galvanized coated weldments to nugget penetration

as-received condition. Certain intermetallic compounds between the base metal and the pure zinc can be seen under high magnification. These are diffusion products and represent a possible source of difficulty in making a good weld. However, new techniques in hot dipping have limited the brittle diffusion products in galvanized steel. This, in addition to the fact that the welding process takes place in only a small fraction of the coating process time, suggests that brittle formations in weld nuggets result principally from trapped iron-rich zinc alloys in the nugget area.

The material used in this investigation was 0.032-in. steel covered on each side by a 0.0017-in. zinc coating which, if melted without zinc loss, would yield an alloy composed of 90% iron and 10% zinc by weight. Such an alloy would be an iron-rich solid solution and would retain the characteristics of the steel base metal. It is, however, not likely that this much zinc would find its way into the nugget materials as the electrode pressure forces much of the zinc away from the weld area during the first stages of the heating, and some zinc boils before the base metal melts. Considering all factors, an alloy very low in zinc should result if a single equilibrium is reached throughout the nugget volumes, but the welding operation often stops short of an over-all equilibrium and provides more severe concentration of zinc. This is shown by the macrographs of Fig. 13. Welds A and B have progressed in a normal fashion with increasing current. Weld C, which should show a well-formed nugget at the center of the section, has an inclusion along the joint line. The fact that it is narrow and along the joint line indicates that the concentration of zinc at the weldment interface resulted in a brittle high-zinc alloy rather than in the composition of weld metal which would have corresponded to overall equilibrium in nugget volume. This brittle material flaked out during polishing for metallurgical examination.

Both types of defects are shown in Weld D. The larger inclusion in the nugget material closely resembles the results of excessive heat in welded uncoated material. This typifies a gaseous inclusion and is due to trapped gas which expands when the electrode force is removed from the hot weldments. The small inclusions appear along the joint line and resemble trapped zinc-rich iron alloys which have pulled out during polishing. X-ray analysis indicates that this is a random phenomenon both in coated and uncoated material. It is not possible, however, to define just how these defects may be avoided by selective machine settings other than avoiding excessive welding heats.

The micrograph shown in Fig. 14 is a portion of Weld B in Fig. 13 and clearly shows the structure of the dark bands seen in the various macrographs. The martensitic structures are separated slightly by a lighter band of iron alloyed with zinc and no dendritic structure is in evidence. This is a characteristic weld structure obtained in most welds of this gage material.

Hardness tests run on coated-weldment nuggets were similar to those run on uncoated weldments. The alloyed bands along the joint line of welds produced at low heats had hardness which indicated high zinc alloying. The acceptable nugget penetrations gave consistent hardness readings.

Zinc-coated weldments show an interesting variation in the strength properties of resistance welds. Once grain growth has started, uncoated weldments produce welds whose strengths increase rapidly to a maximum with increased welding current, but there is little joint strength until nugget formation is observed. A weld made with zinc-coated weldments may show almost fifty percent of the maximum joint strength without any sign of nugget formation. This is due to the soldering and alloying action of the zinc coatings at low heats.

Resulting Surface Conditions

Welds of satisfactory penetration retain little zinc coating in the weld area. Much of the original coating material has been displaced to the sides of the weld by electrode forces and little or no zinc was evident on welds made at maximum heat which suggested that there might be severe impairment of corrosion resistance in the weld area of these weldments.

The results of specific corrosion tests in sodium sulfate, however, showed that

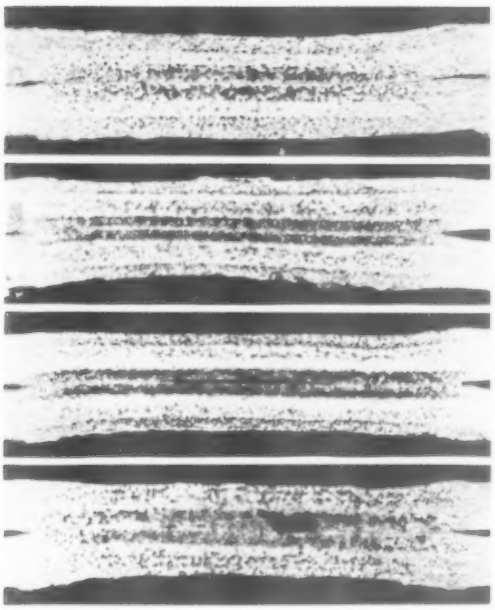

Fig. 13 Defects encountered in seam-welded galvanized steel. Electrode force 1200 lb, welding speed 60 ipm, continuous current, and 22-gage weldment

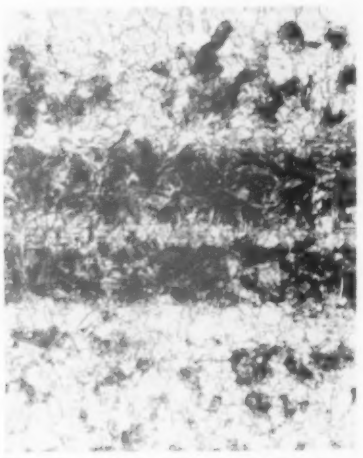

Fig. 14 Micrograph showing structure of weld taken from center of Weld B in Fig. 13

the weld areas retained considerable corrosion resistance because of the alloying effect of the zinc at the surface. The weld surface was better than 90% effective against corrosion in the immersion test, and no pitting or severe corrosive activity was apparent. Metal next to the weld was subjected to knife-edge attack which is a type of corrosion associated with galvanic couples. (Galvanic couples consist of two dissimilar metals in electrical contact and immersed in an electrolyte.) A dissimilar metal was formed when the heat of welding changed the composition of the metal in the weld area. The weld metal, a zinc alloy at the surface, formed a couple with the unaffected zinc coating and fine cracks appeared near the weld.

A type of grain-boundary attack was observed in both welded and unwelded testpieces; the attack in the welded specimen was severe adjacent to the weld area and seemed to start at the edge of the weld. This form of attack is evidently not directly related to the welding operation.

Conclusions

Based on the data presented in this report, the following factors are directly related to the presence of a zinc coating on the weldments in the weld area:

1. Interrupted welding currents having long "off" times are undesirable. Tests showed considerable arcing and flashing as the "off" times were increased. However, good welds were obtained using 18,000–19,000 amp, 4–5 cycles, 1 cycle off, 1200-lb electrode force and a 60-ipm welding speed.

2. Continuous current yields good nugget penetration over a wide current range. The use of continuous current at a high percent heat approaches a continuous operation in which the zinc coating flows away from and back to the weld area smoothly, causing less disturbance of the welding operation. A continuous current of 16,000 amp, electrode force of 1200 lb and a welding speed of 60 ipm produced welds of good penetration.

3. Higher welding currents are required to produce nugget penetrations equal to those of uncoated material using similar settings.

4. Oxide films, associated with zinc, are responsible for higher electrode force requirements in obtaining optimum penetration ranges. High electrode force can be used to rupture these surface films. Satisfactory machine settings, having electrode forces ranging from 700 to 1200 lb, can be made.

5. A form of continuous electrode dressing and edge width control is desirable to prevent an excessive zinc buildup on the welding faces of the electrodes.

6. Welds of satisfactory penetration retained little zinc coating in the weld area, but had considerable corrosion resistance.

PROPOSED PROCEDURE FOR TESTING SHEAR STRENGTH OF BRAZED JOINTS

Authors propose that a standard shear-test specimen, test procedure and test evaluation be universally adopted for brazed joints

BY F. M. MILLER AND R. L. PEASLEE

SYNOPSIS. It is proposed that a standard specimen and procedure for testing the shear strength of brazed joints be universally adopted, similar to what has been done for testing tensile strength of metals. The shear-strength data in current literature are based on many different specimen designs and test procedures. Laboratory tests clearly show that shear-strength data ranging from 10,000 to 65,000 psi can be obtained by varying the shear-test specimen while brazing alloy, base metal and brazing procedure remain the same. With this in mind, it is apparent that current laboratory data and published literature on shear strength of brazed joints is misleading and, consequently, of little value to the designer and welding engineer. The proposed specimen should fulfill the following requirements:

1. Be simple in design and inexpensive to make.
2. Be brazeable without forming fillets.
3. The joint area should be small enough so that the base metal is not stressed over ½ its yield point.
4. The geometry should be such that the minimum of localized stresses are encountered.

Applications for proposed test specimen:

1. For determining unit shear strength of brazed joints as affected by the brazing procedure, brazing alloy and base metal.
2. To supply uniform and accurate design data for the production of brazed components.

Introduction and Theoretical Considerations

The increased use of brazed joints on highly stressed components for room- and elevated-temperature use has brought about a demand by designers for more data on the strength of brazed joints. Tensile-shear test data is more desirable than butt-tensile strength, or compressive-shear data, because the greatest majority of brazed joints are subjected to tensile-shear stresses in service. This is a difficult problem, because the reported shear strength of a brazed joint varies greatly with the design of the specimen, and according to how the unit stress is calculated. It seems that every researcher on brazing uses a different specimen design and theoretical approach to the shear strength.[1-12] As a result, the published shear values are not suitable for design purposes. Before adequate data can be obtained for design use, several factors will have to be considered. One factor pertains to the theoretical definition of shear strength, and another pertains to the design of the test bar. As an attempt to furnish such desired data, we advocate, with the above two factors in mind, that a standard shear-test specimen, test procedure and test evaluation be developed and universally adopted. This would be similar to what was accomplished by the adoption of the standard tensile-test procedure for metals.

Shear strength is considered by stress analysis engineers to be the resistance to slippage, while the cohesive strength of a material is considered to be the resistance to separation.[7] However, in spite of all of the strength-test procedures, there has never been developed a completely accurate method for finding the true slip resistance or true cohesive strength of a metal, as Gensamer clearly points out.[7] However, this analogy becomes very complex, and for certain practical applications we can look at the situation from a different angle. One thing should be pointed out here, and that is, in any kind of testing the value of the test data is strictly dependent on the interpretation of the data and how it is put to use. This will be discussed in detail later.

For this problem we will consider shear as the direction of applying a force. In a brazed joint, then, if the direction of the major stress is parallel to the joint area, we will consider it under shear loading. This is in contrast to the fact that if the direction of the major stress is perpendicular to the joint area, it will be in butt tension. For the time being we will have to ignore the fine points about the true state of stress, such as normal and shear stresses, that occurs in any type of loading.

To get back to the brazed joint, under shear loading the first problem that must be considered is the fact that the stresses are not uniformly distributed throughout the joint area. The degree of stress concentration, of course, depends on the joint design. But, in any case, the stresses are always concentrated at the edges of the joint. What these stresses actually are, could only be determined by complicated stress analysis procedures and mathematical calculations.[5-14] Now, if the breaking load of the previously discussed brazed joint under shear were divided by its cross-sectional area and reported as the shear strength in psi, it could be very misleading as will be pointed out later. This does not necessarily mean that shear tests are impossible, and that nothing practical can be done to evaluate the behavior of a joint under tensile-shear loading. It does mean, however, that a standard method of testing must be devised, and the correct evaluation of the test figures be conducted. This is no different from standard tensile testing. It has been found that data from tensile-strength tests must be used differently for every type of design. For example, ductility values obtained from tensile-strength tests have very little use in pressure-vessel design, as brought out by Zanstin[9] in his analogy of the British Comet failures. For the reasons stated before, an extensive study and experimental program was conducted in an attempt to develop a practical method of testing and evaluating the strength of a brazed joint when subjected to tensile-shear stresses.

Preliminary Studies and Tests

Shearing loads can be applied either in tension or compression. This project involved experiments using both types of loading, but the majority of the research was conducted on tensile-shear loading for the reasons stated previously. For the sake of clarity, this project pertains to high-temperature resistance

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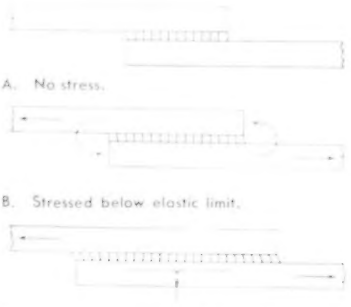


Fig. 1 Diagram showing stress distribution in a typical brazed lap joint, when joint is stressed below its yield point

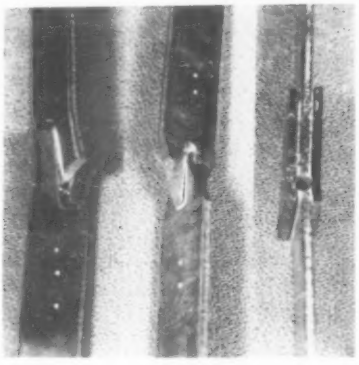
(Courtesy Handy and Harman)

metals brazed with hard filler metals. Many of the concepts, however, may be true for any type of brazed joint.

In any type of testing, the best method would always be actual service tests and the next best would be a simulated service test. In the case of brazed joints, the testing of the actual part or a section of the part, such as in the case of a sheet-metal component, would give the best picture of what would happen in service. However, it is imperative to have preliminary data to predict what might be expected before the parts are fabricated. This is the reason for attempting to develop some type of standard shear-test procedure for brazed joints.

The first thing studied was the effect of stress concentrations in a brazed joint when it is subjected to a tensile-shear force.

In all types of tensile-shear joints, the point of maximum stress is always at the edges of the joint, and these stresses are reduced toward the center of the joint. However, the amount of stress concentration varies greatly with the joint design, and with the ratio of joint area to the base-metal crosssectional area (length of overlap). For example, if the overlap is many times the base metal thickness, the stress will be zero at the center of the joint, as well as at a certain distance on each side of the center, as shown by DeBruyne.[4] In this case, then, the majority of the joint area contributes nothing to the strength of the component. Figure 1 shows the stress concentrations of such a joint. This figure shows that much of the joint area is not stressed at all until after the part starts to fail. However, in a single-lap joint another factor arises as the stress is increased. The specimen tends to rotate, and that puts the joints under bending loads. These factors indicate that the breaking load of such a specimen, divided by the joint area, would result in a figure that is no



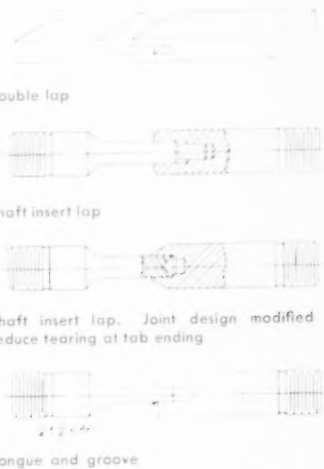


Fig. 2a Currently-used shear specimens

indication at all of the actual cohesive strength of the brazed bond.

As stated previously, there are a great number of shear-specimen designs that have been used on previous research work. Figures 2*a* and 2*b* show some of the specimens used by authorities on recent work.

There are definite advantages and disadvantages for all types, but three major factors are prominent, namely: the amount of stress concentration in the specimen, manufacturing difficulties and cost. Unfortunately, the specimen designs that produce the least stress concentrations are the ones that are the most expensive and difficult to make. For example, the single-lap joint, which is the easiest to make, probably produces the most stress concentrations,

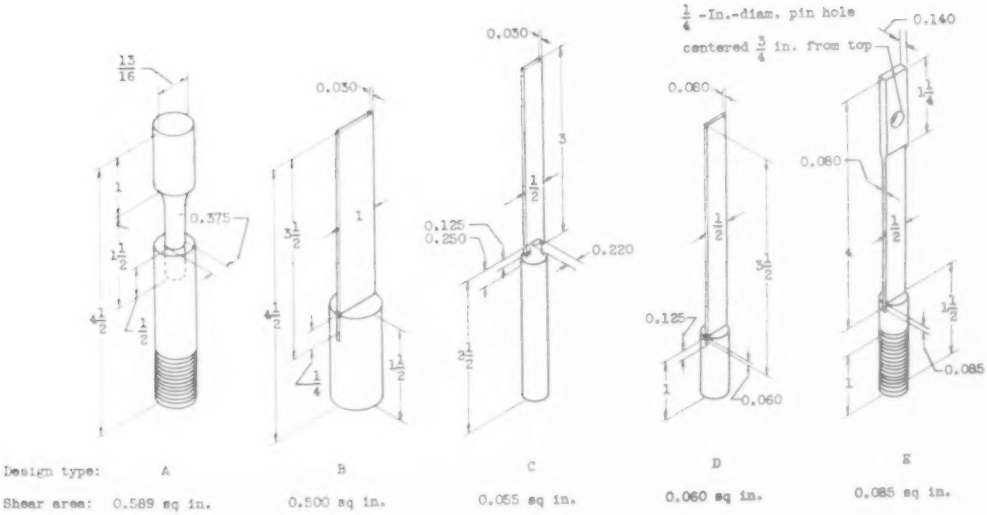


Fig. 2b Various experimental shear-specimen designs

(Courtesy National Advisory Committee for Aeronautics)

while the shaft-insert type of lap, such as shown in Fig. 2*a*, produces the least amount. Another factor pertaining to the test-bar design is its size. It has been stated by authorities that the larger the size of the shear-test specimen, the greater will be the stress concentrations and resulting inaccuracies. To show the difficulties in making a good shear-test specimen, consider the following design consisting of a 0.250-in. diam shaft insert-type tensile-shear specimen. In order to keep the stresses in the base metal low enough so that the fracture will be in the joint, the brazed area will be equal to one fourth of the base-metal cross-sectional area. This will necessitate an overlap of approximately 0.016 in. between the two portions of the specimen. With a joint this small, it will also be necessary to remove both fillets because they would influence the final strength more than the total joint area. Holding these close dimensions, plus the joint clearances, plus the elimination of fillets to obtain the necessary accuracy, is virtually impossible for quality-control work.

On a simpler joint, such as a double-lap joint, or a tongue and groove specimen (Fig. 2*b*), the overlap, using an inside leg of $\frac{1}{4}$ in. thickness, would only be $\frac{1}{32}$ of an inch. Even on the simpler specimens such dimensions would be difficult to hold accurately. It should not be forgotten, however, that these minute laps or the resulting joint areas cannot be noticeably increased without increasing the stress on the base metal beyond a desirable limit. For this reason, the following test procedure and specimen design is recommended.

Proposed Specimen

The first thing considered, before an actual specimen was designed, was the overlap. In a brazed joint subjected to shear loading, as the overlap increases, the joint load-carrying capacity (in pounds) increases to a maximum, where the base metal always fails. Also, as the overlap increases, the unit shear strength decreases, if the breaking load is divided by the joint area. However, as the joint area is decreased, the unit stress in the base metal is also decreased. Therefore, it was decided that the criterion which should determine the joint area would be based on the maximum unit stress desirable in the base metal. In order to make the test bar fail in the joint, rather than in the base metal, it was decided that the desirable base metal stress should be in the neighborhood of $\frac{1}{2}$ the yield point of the base metal. Tests have shown that on ductile base metals the joint area should be about $\frac{1}{4}$ the base-metal area in order to satisfy the previously-mentioned requirements, as will be shown later. The above determinations, then, established what the overlap should be in the brazed shear-test specimen.

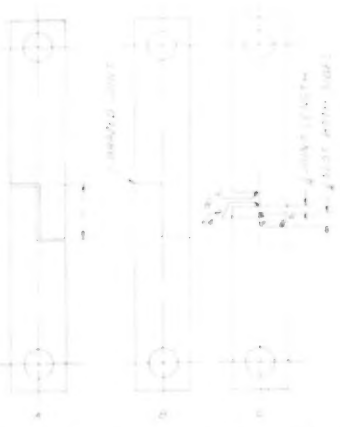


Fig. 3 Proposed single-lap specimen for shear testing of brazed joints

A. Notched bars before brazing. B. After brazing. C. Slotted after brazing. Material: 1- x $\frac{1}{8}$-in. strip

The next factor that had to be determined was what specific type of specimen should be used. As stated previously, when the overlap is reduced drastically, it becomes a very difficult job to hold dimensions accurately. Also, on several of the described specimens shown in Fig. 2, the fillet would have a greater effect on the joint load-carrying capacity than the actual brazed area. The machining problems encountered in removing these fillets, without overstressing the joint, are too impractical for quality-control tests, especially if the specimen is brazed with a hard material.

After much study and experimentation, a single-lap joint was devised where the overlap and resulting joint area could be maintained accurately, and where there would be no fillet effect whatever. Also, the general design is simple enough, so that good specimens could be made in almost any shop. Figure 3*a* is a drawing of this specimen. It can be seen that instead of lapping two pieces of sheet metal together across the width, they were lapped edgewise. Holes were drilled in one end of the test-bar legs, while the other end of the legs was notched in such a way that the joint would fall in the longitudinal center of the test specimen when the legs were brazed together. There are two major reasons for lapping the specimen edgewise. First, it is then possible to have a smaller joint area in relation to the base-metal cross-sectional area, without an intolerable specimen size. Second, the fillet effect can be completely eliminated.

In order to control the lap accurately and reduce the hazards of getting a poor braze, the specimen halves were brazed together across all mating surfaces, as shown in Fig. 3*b*. After brazing, the specimens are carefully inspected and all excess brazing alloy is ground off the faces. The specimen is then slotted, as shown in Fig. 3*c*. The brazed area between the slots is now the joint area of the test specimen, and will be in shear

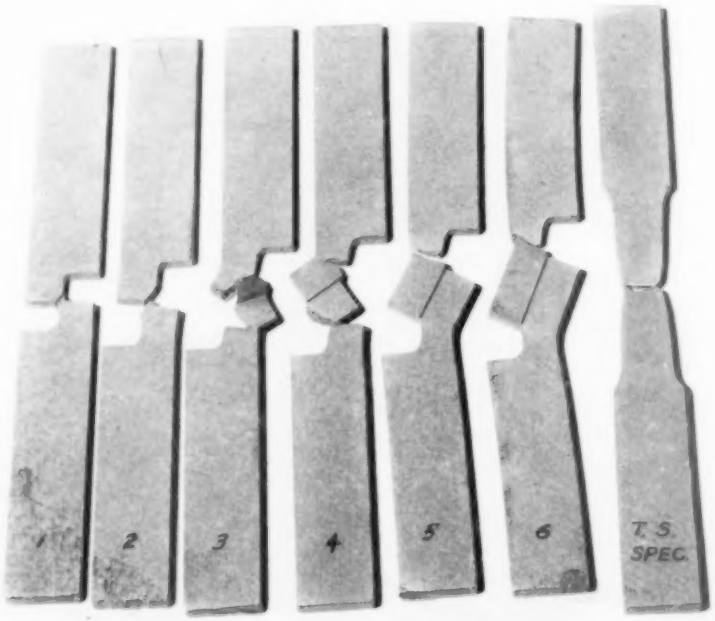


Fig. 4 Mild-steel simulated-shear specimens

Fig. 5 Single-lap brazed shear specimen before and after test

when the specimen is pulled in the tensile machine. The rest of the brazed area is not under load and has no effect on the specimen.

It was stated previously that the most desirable overlap was determined by experiment to be about $^1/_4$ T. This figure was arrived at after conducting several experiments.

These experiments were conducted on a series of unbrazed specimens. These specimens were made the same as the one shown in Fig. 3c, except the area in shear varied from $^1/_4$ T to 2T. Instead of brazing two pieces together, as shown in Fig. 3, the specimens were one solid piece with the slots cut to resemble the various overlaps. This was done to eliminate the brazing variables. The resultant figures, then, were strictly affected only by the length of the shear area and the stress concentration. Figure 4 shows the broken specimens, and Table 1 shows the test results, including the various "joint" areas.

It must be understood that this test is not, in any way, attempting to determine the shear strength of the base material. It is strictly for the purpose of determining the effect of geometry on the breaking strength of a joint without actually making a braze.

By studying the fractured bars, it can be seen that all of these test specimens attempt to rotate. However, the bar, with the overlap equal to $^1/_4$T to $^3/_4$T, fractured at a 45-deg angle from the shear area. This is typical of failures that are subjected to shear stressing. Also it can be seen that as the shear area increases, the breaking load eventually becomes the actual tear strength across the base metal.

The most surprising thing about this test is the fact that the shear strength of Specimen 1 was actually higher than the ultimate tensile strength. This is because the shear fracture took place at a 45-deg angle to the fictitious brazed joint, thus actually fracturing across an area larger than the calculated area. The most significant thing about this test, however, is to indicate that in a single-lap brazed joint of mild steel, the so-called shear strength could vary from 65,300 to 28,600 psi, or less, depending on the amount of overlap. This test, then, verifies the statement made at the beginning, i.e., "If the breaking load of a brazed joint under shear is divided by its cross-sectional area, the results can be very misleading." The test also shows that in order to get the truest results, the joint area should be designed so that the average stress on the base metal will be about $^1/_2$ of the yield point. In the case of the previously-proposed specimen, the joint area relative to base-metal cross-sectional area should be about 1 to 4, which, in this case, would be an overlap of $^1/_4$T.

In view of the above tests, a series of brazed joints was made using the specimens shown in Fig. 3. The base metal was Type 302 stainless steel, brazed with AMS4775A at 2150° F, 30 min at heat, $^1/_4$ in. ($^1/_4$T) overlap. Figure 5 shows two of these specimens unbroken, and two specimens after testing. Table 2 shows the test results.

It is realized that, on any single-lap joint, the stress concentrations are worse than on certain other types of joints, such as the shaft insert (plug and ring) type. However, the fact still remains, as mentioned before, that the other considerations in the manufacture of the test bar, such as joint clearance, elimination of fillet effects, ease of controlling the brazing variables and other such things, are more than compensated for in this design.

Table 1 Results of Shear Tests on Simulated Specimen

Base metal: mild steel
Ultimate tensile strength: 61,170 psi
Base-metal area: 0.125 sq in.

Specimen	*Breaking load*	*Average stress shear area, psi*	*Average stress base metal C/S, psi*	*Ratio of shear area to base metal C/S area*	*Shear area, sq in.*
1	2025	65,300	16,200	1 to 4	0.031
2	3700	59,675	29,600	1 to 2	0.062
3	5050	54,725	40,400	3 to 4	0.094
4	5275	42,200	42,200	1 to 1	0.125
5	6900	32,450	48,000	3 to 2	0.188
6	7150	28,600	57,200	2 to 1	0.250
7	7650*	20,400†	U.T.S. 61,170	3 to 1	0.375
8	7650*	15,300†	U.T.S. 61,170	4 to 1	0.500

* Calculated from tensile-strength bar.
† Calculated from results of 1 above.

Compression-Shear Test Procedures

Even though it was previously mentioned that the prime interest in this paper pertains to tensile-shear testing, a few words should be said about compression shear. The results of compression-shear testing are quite different from those obtained in tension, but the fundamental theoretical factors are the same. For example, there are still stress concentrations that vary with the design of the test specimen. Also, the shear-strength results will vary with the specimen, and with the method of compression. Bredzs[1] describes several test specimens and shows how these stresses concentrate (Fig. 6). The authors have experimented quite extensively with this type of specimen. In fact the top was

Table 2 Results of Shear Tests Using New Brazed Specimen Design

Base metal: 302 stainless steel
Brazing alloy: AMS4775A
Brazing temperature: 2150° F
Overlap: 0.125 in.
Joint area: 0.017 sq in.
Base-metal area: 0.07 in.

Specimen	*Breaking load, lb*	*Average shear stress joint area, psi*	*Average stress in base-metal cross section, psi*
1	900	53,000	12,800
2	900	53,000	12,800
3	950	55,900	13,570
4	875	51,500	12,500
5	975	57,300	13,900

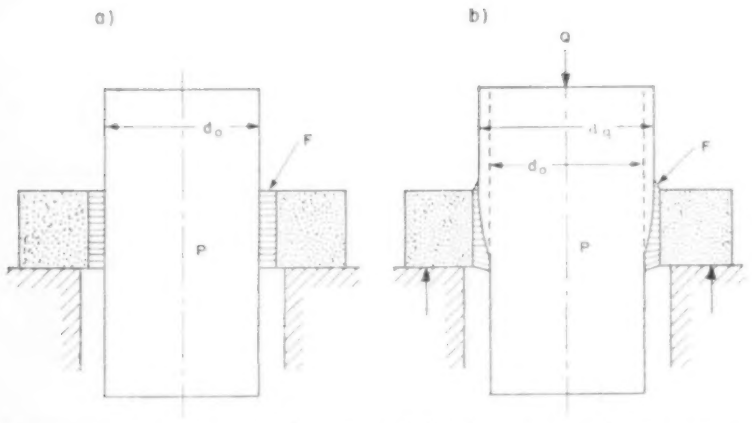


Fig. 6 Plug and ring device (compression) for shear-strength determination in brazed joints

(a) Before loading and (b) after loading. Due to the expansion of the plug, *P*, under the load, *Q*, the diameter of the plug increases from d_o to d_q. This expansion results in a combination of compression and shear stresses in the filler-metal layer, *F*. The compressive stresses are especially large in the upper part of the filler-metal layer. (Courtesy Frankford Arsenal)

cut off the plug to eliminate the bulging effect on a few specimens. However, the tests results still varied greatly with the sharpness of the punch and die that pushed the brazed plug out of the ring. Basically, the sharper the punch and die, the lower the shear strength will be, everything else remaining equal.

Bredzs also recommends another type of shear specimen and testing fixture that is claimed to approximate more closely the true shear strength of a brazed joint (Figs. 7*a*, 7*b* and 7*c*). It is agreed that this test specimen and fixture, if carefully made, will probably develop less stress concentrations than the single-lap tensile-shear specimen, or a plug-and-ring compression-shear test specimen. However, it is questionable whether a uniform shear stress is actually developed throughout the cross section, or whether such a thing as "true shear strength" is actually developed. On this specimen, the stresses are concentrated at the top and bottom, and are very low at the center of the joint until the specimen starts to yield. The same thing is true with this specimen as is true with the plug and ring type. The design of the fixture will greatly influence the results. The following are a few of the factors that could influence the test results if everything else remained the same: (1) clearance between the sliding fixtures, (2) sharpness of the mating edges of the fixture holes, and (3) amount that the fixture "captures" the specimen. This specimen resembles a rivet, and it would be a very good quantitative test for parts that are so stressed in service. However, caution should be used in assuming that the shear-strength values from this test would be directly applicable to any type of brazed joint.

Generally speaking, any type of compression-shear specimen will produce fictitiously high results while tensile-shear specimens will produce fictitiously low results. The exact amount of inaccuracy of course, varies greatly with each specific specimen design.

Discussion and Evaluation of Test Results

As every experienced tester knows, any test has its pitfalls and limitations. The above proposed shear-test method is no exception. There are many theoretical reasons by which this test could be argued to be inadequate for determining the unit joint strength in tensile shear of ductile base metals brazed with hard filler metals. For instance, we recommend the use of a test bar with a short overlap to minimize the effect of stress concentrations, and to cause failure in the joint, rather than the base

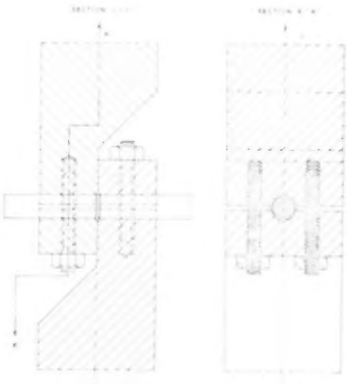


Fig. 7*b* Details of test apparatus for above shear-test device

(Courtesy Frankford Arsenal)

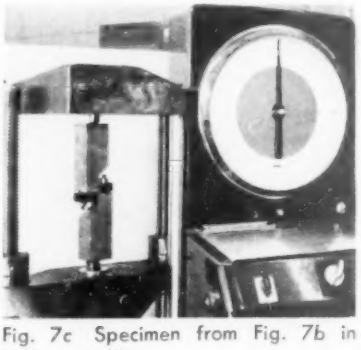


Fig. 7*c* Specimen from Fig. 7*b* in testing machine

(Courtesy Frankford Arsenal)

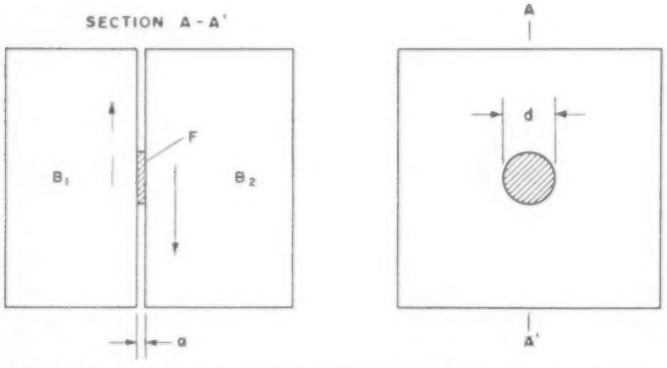


Fig. 7*a* Shear-test device for determination of "true" shear strength-joint thickness curves of the brazed joints under almost ideal test conditions

The conditions of this test would be absolutely ideal if the base metal were absolutely rigid and inelastic and the thickness of the filler-metal disk, *F*, were infinitesimal. Since every base metal has some elastic properties, some deformation of the base metal will take place in the base-metal layer adjacent to the filler metal disk, *F*. In order to minimize this deformation as much as possible, the base-metal blocks B_1 and B_2 have to be very large

metal. Now, in an actual brazed joint for service, the reverse should be done. The overlap should be sufficient to give the joint more load-carrying capacity than the base metal. This approach, then, disputes the need for such data as "unit shear strength in psi" of brazed joints. In fact, the writers are reluctant at the present time to furnish unit shear-strength data on brazed joints for two reasons. First, because there is no standard approach to such testing. Second, because most current researchers in the field report unit shear-strength data without considering the significance of the test procedure, or without recording the design of shear specimen used. This has resulted in an abnormally-wide range of results in research projects of a similar nature.

However, many design engineers are constantly demanding unit-shear-strength data for brazed joints before they will specify brazing in their designs. Also, brazing-alloy users are constantly demanding unit-shear-strength data for certain brazing alloys before they will buy them. Also, it has been found that certain brazing-alloy suppliers, and brazing sources, are submitting information and test data that is misleading. The argument is this: if unit-shear test data have to be presented, it should be presented with the following three factors in mind:

1. A standard test bar should be universally adopted.
2. The particular test bar used should produce the least amount of localized stresses, should not have fillets, should be relatively inexpensive to make, should be relatively easy to braze and should be designed so that the base metal is not stressed over ½ its yield point.
3. The evaluation of results should be standardized, and the evaluation should consider the significance of test-bar design.

It is believed that the specimen proposed in this report fits the above requirements as closely as anything yet developed. If the test data are properly

Table 3 Brazing Shear-Test Log Sheet

Log sheet no. _____ Date _____
Specimen no's. _____
Purpose of test _____

Test specimen data
- Base metal (analysis & condition) _____
- H.T. after brazing, if any _____
- Brazing alloy, composition _____ Form _____
- Clearance, before brazing _____ After brazing _____
- Overlap, inches _____ T (ratio joint/base metal area) _____
- Joint surface preparation _____ (Blasted, pickled, ground, etc.)
- Joint quality after brazing _____ (% Porosity-undercutting)

Heating equipment
- Method of heating (furnace, induction, torch) _____
- Type of retort (bell, tube, muffle) _____ size _____
- Seal geometry (if sand seal) _____
- Flow rate thru seal (cu ft gas/linear inch seal) _____

Atmosphere
- Type _____ (D.P. or vacuum pressure) _____
- Flow rate (retort volume, per hour) _____
- Vacuum pumping rate (if used) mechanical _____ diffusion _____

Brazing Cycle
- Brazing temperature _____ Braze alloy liquid _____ Braze alloy solid _____
- Heat time, minutes
  - To 1200° F _____ 1200° F to solidus _____ Solidus to Liquid _____
  - Liquidus to braze temperature _____ Time at temperature _____
- Cooling time, minutes
  - To solidus _____ To 1200° F _____ To 600° F _____

Test results

Specimen no.	Joint area	Breaking load	Average stress base metal C/S	Average shear stress joint area	Visual exam of fracture

evaluated, they should find practical use. The proposed test specimen could be used either for the evaluation of factors in the brazing operation or for use in designing brazed components for service. For evaluation of brazing operations this test bar could be used to determine the effect of base metals and brazing alloys on joint strength and also such other variables as atmosphere, temperature, heating rate and joint clearance on joint unit-shear strength. Of course only one of the above mentioned variables should be evaluated at one time. All variables except the one being evaluated must be held constant if the results are to be authentic. For this reason, whenever unit-shear strength values are reported using the standard test bar, the following brazing conditions should always be reported: base metal, brazing alloy, joint clearance, brazing temperature, heating rate, time at heat and atmosphere (type and dew point). A work sheet such as shown in Table 3 could be used for recording necessary data when using this test procedure.

When using the proposed test procedure for evaluating factors in the brazing operation, the unit-shear strength can be computed as follows:

$$S = \frac{F}{a}$$

where

S = average unit strength in tensile shear of brazed joint in test bar.
F = failure load in pounds.
a = area of brazed joint in test bar.

The proposed test is not recommended as the best quantitative determination of load-carrying capacities of brazed components for service. However, a close prediction can be obtained which should be valuable in the initial design of components.

On most brazed components it is common practice to overlap the joint at least four times the weaker base-metal thickness (4T). This has been previously established by test to be about the minimum overlap to insure safely maximum joint load-carrying capacity. There are other factors which sometimes arise where the joint overlap may have to be more or less than 4T.

The following procedure should be followed when using the proposed test bar for designing brazed components for service. The load-carrying capacity should be computed as follows:

(*a*) Divide the *unit* shear strength obtained on the standard test specimen by a factor of four. This is necessary to compensate for the fact that the service joint is not stressed in the same way as the base metal or as the standard test bar.

(*b*) Multiply the joint area by the figure obtained in (*a*) above. This will be the approximate load-carrying capacity of the brazed structure.

(*c*) If the joint overlap is more than 4T, the divisor factor should be *increased the same amount*. If the joint overlap is less than 4T, the divisor factor should remain four.

The above can be computed by the following formula:

$$L = \frac{SA}{4 + X}$$

where

L = load-carrying capacity of brazed structure.
S = unit shear strength of brazed test bar.
A = area of brazed joint.
X = overlaps (T) in *excess* of 4.

It must be realized that if the test bar values are to be used to calculate L, the brazed structure must have the same base metal, same brazing alloy and be brazed under exactly the same conditions as the test bar.

As previously mentioned, the *best* method of testing the load-carrying capacity of a brazed component designed for service would be to test the actual part or a simulated part. On a simulated part, the joint should have the same geometry as the actual part. It then could be pulled to a given amount of elongation, such as 5%, for example, or until failure, whichever occurs first. One thing is imperative, however—the results must be correctly expressed. On a service part, or simulated part, *it is incorrect to divide the failure load by the joint area and express the results as "unit-shear strength in psi."* These results could be correctly expressed as follows:

"Strength of joint in tensile shear, expressed in psi of the base-metal cross section."

The above can be computed by the following formula:

$$Y = \frac{F}{B}$$

where

Y = shear strength of joint, per unit area of base metal.
F = failure load in pounds.
B = base-metal cross-sectional area, weakest member of joint.

The above methods are relatively simple and will reveal true instead of fictitious values. These values should be useful to metallurgists and welding engineers to help evaluate brazing alloys and brazing methods. Also these values should be useful to design engineers by enabling them to design brazed structures more accurately and safely.

Recommendations

It is hoped that engineers, designers and fabricators, using or desirous of using brazed joints, will give this matter serious thought and consideration. In order to derive the maximum benefits from the recent discoveries in the field of brazing, there is an urgent need for a new approach to strength testing. The proposed method of shear testing of brazed joints may not be the last word, but it is strongly recommended that industry adopt at least some of these principles, or similar ones, and make them standard. This is necessary in order to fulfill the above need.

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DUCTILITY AND ENERGY RELATIONS IN CHARPY TESTS OF STRUCTURAL STEELS

Paper examines the applicability of an invariant notch-ductility criterion to a wide range of steels whose notch toughness is critical

BY J. H. GROSS AND R. D. STOUT

ABSTRACT. Despite its shortcomings, the Charpy test remains the most generally used test to evaluate the resistance of steels to brittle failure in low-temperature service. While a direct correlation of Charpy values with performance of carbon structural steel in welded ships was demonstrated, evidence has been advanced to show that other grades of steel, particularly low-alloy steels, depart from correlation unless higher levels of energy absorption are arbitrarily selected to match the Charpy transition temperature to service failure.

This paper presents extensive data which suggest that the energy-absorption criterion is unsatisfactory in part because it is influenced by the strength level of the steel. This is to say that energy absorption is controlled by two factors: (1) the strength of the steel which regulates the force required to deform the specimen, and (2) the ductility of the steel which determines the distance through which the force acts during testing. Energy absorption is proportional to the product of these two factors. Since loss of notch toughness is due to loss in ductility rather than strength, a criterion which evaluates notch ductility instead of notch toughness (i.e., energy) should serve as a more significant and universal measure of the service properties of structural steels.

An index of ductility can readily be obtained from Charpy bars by measuring the lateral expansion of the bar at the compression side of the bar directly opposite the notch. Tests on carbon and low-alloy steels show that the expansion correlates linearly with energy absorption for a given steel, but that each steel has a singular relation. If from these curves, the energy absorption is read for a stated constant expansion, the energy absorption at a given ductility is obtained. When the energy levels so obtained are plotted against the strengths of the steels tested, a direct correlation results. Thus, to insure a certain notch ductility in a steel, one must specify an energy-absorption level dependent on the strength of the steel of interest.

If it is notch ductility which is important to low-temperature service performance, it appears to be logical to adopt a ductility measurement in the Charpy test in preference to energy measurements. For example, a lateral expansion of 15 mils gives some indication of correlating well with the various energy levels that have been proposed for the killed and low-alloy steels as well as fitting the 10 ft-lb level valid for the ship steels of various investigations.

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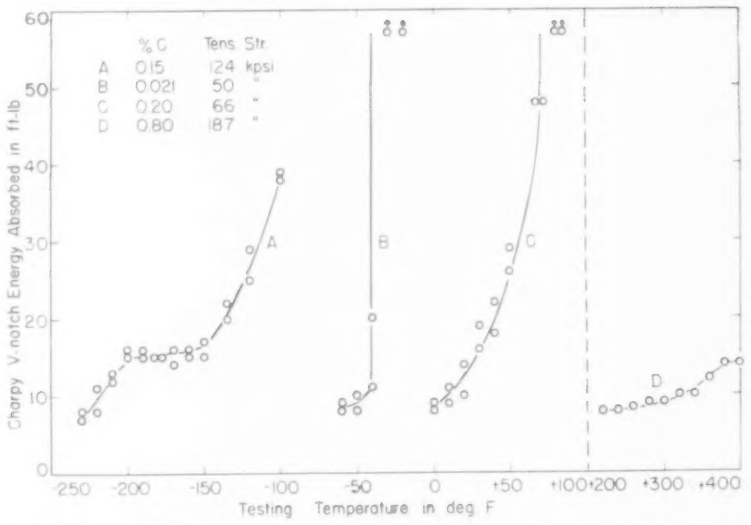

Fig. 1 Effect of carbon content and tensile strength on Charpy V-notch energy transition behavior

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Introduction

Susceptibility to brittle fracture has been evaluated by means of notch-bend tests for many years. However, they were of limited usefulness as design or specification tests for engineering structures because of a lack of correlation with service performance. The first important correlation with service performance was reported by the National Bureau of Standards. These studies[1, 2] related the incidence of ship failures during World War II to the energy absorbed by the various types of plates involved in the failure. Plates in which brittle fracture originated (source plates) through which fracture propagated (thru plates) and in which fracture was arrested (end plates) were examined and their Charpy V-notch energy absorption determined at the failure temperature. The average energy absorptions were 7 ft-lb for source plates, 10 ft-lb for thru plates and 16 ft-lb for end plates. On the basis of this investigation, various energy levels from 10 to 20 ft-lb were selected for determining the Charpy V-notch transition temperature depending on the type of service and factor of safety desired. The use of a 15 ft-lb criterion proved satisfactory for steels of the general type (ABS A & B) included in the Bureau of

Standards study as shown in Fig. 1 for Steel C. Very low carbon materials, such as carbon ferrite with abrupt brittle-to-ductile transition, present no problem. However, many fully-killed plain-carbon, and low-alloy, high-strength steel energy transitions are difficult to interpret at the 15 ft-lb level, particularly when they exhibit a double transition in which the shelf occurs around 15 ft-lb. Moreover, higher carbon materials may not attain a 15 ft-lb level even at temperatures of shear failure in certain microstructural conditions. Thus, it became apparent that the energy criterion applicable to certain types of ship plate was not an invariant criterion which could be indiscriminately applied to other materials.

Further evidence of the deficiencies of an invariant energy criterion is contained in a series of papers[3-8] by the Naval Research Laboratory. In order to determine the effect of a weld-initiated defect on susceptibility to brittle fracture, the NRL Crack-Starter Bulge Test and the NRL Drop-Weight Test were developed. Correlation with various aspects of the Bureau of Standards study was reported for both tests. Specifically, the nil-ductility temperature (NDT) determined from the drop-weight test corresponded to a Charpy V-notch energy absorption of 4–6 ft-lb compared to the NBS range of 5–8 ft-lb for ABS A & B rimmed and semikilled ship plate at ship-failure temperature. However, when the fully killed and low-alloy, high-strength steels were investigated, much higher values of Charpy V-notch energy absorption were observed at a temperature corresponding to the drop-weight NDT as shown in Table 1. Thus it is clear that Charpy V-notch data cannot be correlated to service or to other testing methods by means of a single energy criterion.

One of the important differences between the various steels of Table 1 is the tensile strength which varies from approximately 60 to 120 kpsi. In general, an increase in tensile strength is accompanied by an increase in the Charpy V-notch energy at the NDT. This behavior seems quite reasonable if it can be assumed that the notch ductility required to undergo the 3-deg bend in the drop-weight test is essentially constant for all steels. Because of the higher force required, the energy absorbed by high-strength steels should be considerably greater than that absorbed by lower-strength steels for a given notch ductility. This is demonstrated in Fig. 2. Charpy V-notch bars were loaded at slow strain rates in order to record the load-deflection curve whose integrated area equals the energy absorption. For essentially constant energy

Table 1—Typical Charpy V-Notch, NDT Correlation Values

	Steel	Average Charpy V-notch energy at NDT, ft-lb	Average tensile strength, kpsi
1.	Rimmed steel*	5	60
2.	Semikilled steel*	7	60
3.	ABS-B*	11	60
4.	A 285 (RG)	5	51
5.	A-7 (RW)	7	60
6.	A 201 (RB)	7	57
7.	Norm. HTS*	23	70
8.	4S5 HT (Norm.)	10	68
9.	A 302*	20	90
10.	Quenched and tempered steel	25	125

* Energy values obtained from Table 1, Reference 7; tensile strengths are estimated.

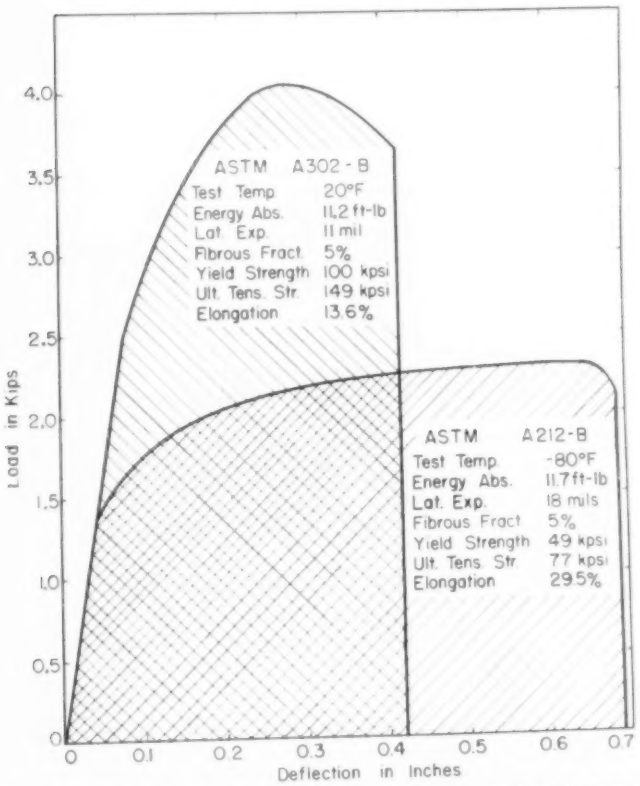

Fig. 2 Load-deflection behavior in slow bend Charpy V-notch test at constant energy absorption for different tensile strengths

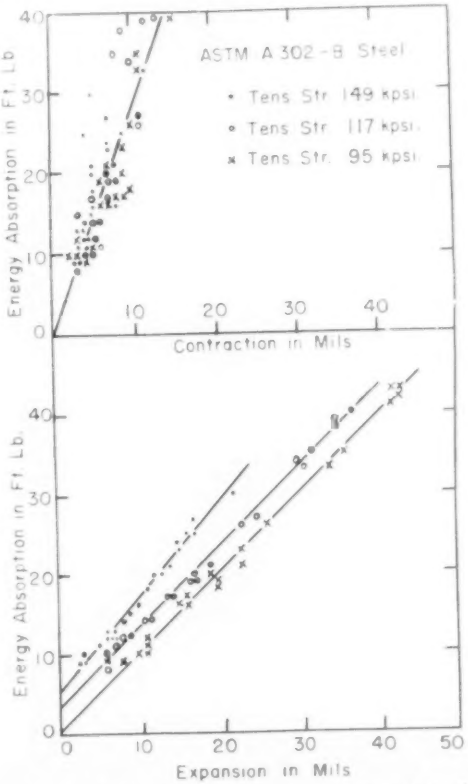
ASTM A 302 - B Steel
• Tens. Str. 149 kpsi
○ Tens. Str. 117 kpsi
× Tens. Str. 95 kpsi
Energy Absorption in Ft. Lb.
Contraction in Mils
Energy Absorption in Ft. Lb.
Expansion in Mils

Fig. 3 Relation of energy absorption to lateral contraction and lateral expansion in Charpy V-notch test

Table 2—Chemical Composition, %

Designation	Code	C	Mn	P	S	Si	Ni	Cr	Mo	V	Ti	Cu	B	Tensile-strength range, kpsi
ASTM A 203	C	0.15	0.61	0.01	0.026	0.22	3.64	0.05						81–132
A 212	D	0.28	0.70	0.01	0.021	0.24								76–93
A 285	A	0.20	0.53	0.02	0.016									66–83
A 302	B	0.20	1.32	0.022	0.030	0.25			0.42					84–149
A 387	S	0.09	0.41	0.013	0.011	0.25		2.18	0.96					89–163
4S-5HT	E	0.15	1.09	0.033	0.028	0.18	0.06	0.06	0.02	0.01	0.009	0.11		70–99
HY-65	G	0.12	0.48	0.013	0.032	0.21	2.16	0.06	0.39	0.11		0.70		96–119
T-1	R	0.15	0.93	0.015	0.022	0.27	0.80	0.48	0.44	0.06			0.0031	118–180
C-1632		0.31	0.62	0.016	0.031	0.17								70–118

Treatments Producing Strength Variations

1. Oil quenching, normalizing, annealing, stress-relieving, tempering
2. Cold work, strain aging at RT, 500, 700 and 1150°F

absorption, the deflection is considerably higher for the lower-strength material, and the lateral expansion is correspondingly higher. Investigations[8, 13] of slow-bend Charpy tests indicate that the slow-bend behavior is indicative of the conventional Charpy impact tests. Consequently, the energy criterion for interpreting Charpy V-notch data must increase with increasing strength in order to maintain a constant notch ductility. The use of an invariant energy criterion results in a continued decrease in notch ductility with increasing strength. This is probably the most important factor in the increase in the Charpy V-notch energy absorption at the NDT with increased strength.

The usefulness of the V-notch Charpy test would be lessened if the energy-absorption criterion requires adjustment for each type of steel or for each heat. This suggests the use of a criterion insensitive to strength variations, a direct measure of notch ductility. Therefore, the lateral contraction at the root of the notch and the lateral expansion on the compression side opposite the notch were examined. Both of these criteria have been used by various investigators. However, no systematic study of the variation in notch-ductility measurements with strength and chemical composition has been made.

It is the intent of this paper to examine the applicability of an invariant notch-ductility criterion to a wide range of steels whose notch toughness is critical.

Experimental Observations

The program of evaluating lateral contraction and lateral expansion as an invariant criterion for the Charpy V-notch test was undertaken because of the wide range of steels and conditions under investigation for the Pressure Vessel Research Committee of the Welding Research Council. The designation, chemical composition and conditions studied are reported in Table 2.

Initially, the lateral contraction and lateral expansion of each Charpy V-notch specimen were determined after testing as well as the energy absorbed and the fracture appearance. Lateral-contraction measurements are considerably more difficult to reproduce than lateral-expansion measurements. Both measurements bear essentially a linear relation to the energy absorption as shown in Fig. 3. However, the variation in energy absorption with tensile strength is revealed more clearly by the lateral expansion than by the lateral contraction. This probably reflects inaccuracies in the measurement of the lateral contraction. Lateral-expansion values can be simply, rapidly and reproducibly determined with an ordinary micrometer calibrated in thousandths of an inch. Consequently, lateral expansion was chosen for the detailed study reported here.

Results and Discussion

A transition curve of the usual shape is obtained when lateral expansion is plotted against testing temperature. This would be expected as a consequence of the generally linear relation between energy absorbed and lateral expansion. Typical examples of the relative be-

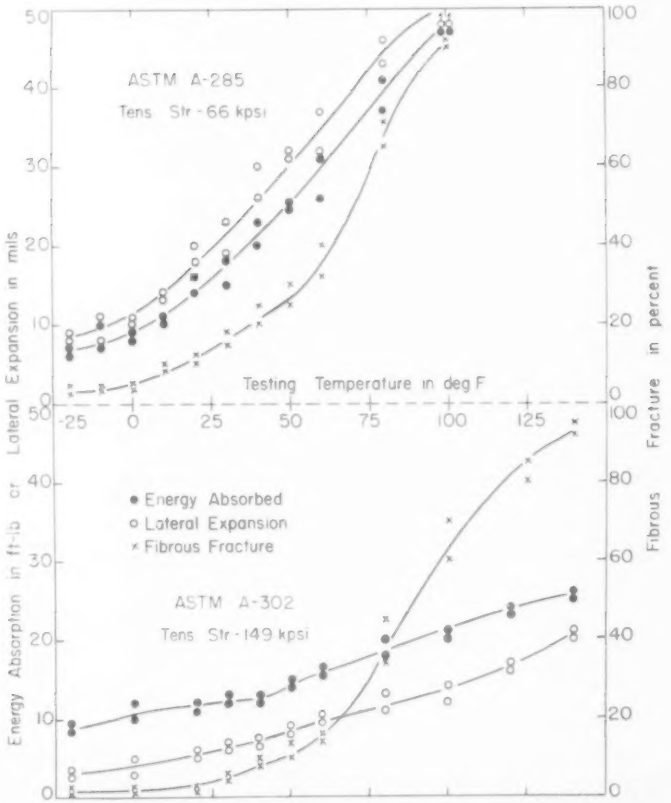

Fig. 4 Influence of tensile strength on the relative position of energy absorption and lateral-expansion transition curves

havior of energy absorption, lateral expansion and fracture appearance with testing temperature are shown in Fig. 4. The influence of the strength factor on the relative position of energy absorption with respect to lateral expansion is immediately apparent. A given level of notch ductility as measured by the lateral expansion corresponds to a much higher energy absorption in the higher strength steel. Thus, notch ductility cannot be inferred from energy absorption values without consideration of the strength factor.

The selection of a transition temperature based on lateral expansion requires the choice of a particular level of expansion. A criterion related to service performance is highly desirable. Such a relation has not been established for lateral expansion. However, it is possible to select a criterion indirectly related to service. Figures 5, 6 and 7 depict the increase in energy absorption with increasing tensile strength at three levels of notch ductility — 10 mils, 15 mils and 20 mils lateral expansion. At a tensile strength of 60,000 psi, which is approximately the average tensile strength of ABS-A and B steels, the energy absorptions average 8, 11 and 14 ft-lb at 10, 15 and 20 mils, respectively. Thus, the 10-mil level of lateral expansion corresponds very closely to "source" plate behavior in the NBS ship plate-fracture correlation. A level of 7 ft-lb would not serve as a specification for ABS-A and B steels since it provides no safety factor to offset scatter. Puzak and Pellini[4] report 10 ft-lb as a realistic level for resistance to crack initiation in the ship-plate steels. This corresponds closely to the 15-mil lateral expansion for similar type steels. Therefore, a lateral expansion of 15 mils appears to be a reasonable criterion for determining transition temperature. Higher levels of lateral expansion can be chosen, if desired, such as the 20-mil value which corresponds to a practical "thru" plate behavior in the NBS study. Probable correlation with service performance cannot be extended to steels other than the NBS ship-plate materials since only a few scattered correlations are available.

Further examination of Figs. 5, 6 and 7 indicates a linear increase in the energy absorbed with increasing tensile strength at any level of notch ductility as measured by lateral expansion. This behavior is consistent with previous observations that an increase in the strength factor results in an increase in the energy absorbed at a constant notch ductility. C1032 bar stock results, denoted by the X's, conform to the same scatter band as plate material. The recommendation[2] of a higher energy criterion for transition-temperature determination for steels other than ABS-A and B is also consistent, since the steels

Table 3

	Corrected energy-absorption criterion		
Tensile strength, kpsi	*10-mil lateral expansion, ft-lb*	*15-mil lateral expansion, ft-lb*	*20-mil lateral expansion, ft-lb*
60	8	11	14
70	9	12	16
80	11	14	19
90	12	16	21
100	13	18	23
110	15	20	26
120	16	21	28
130	17	23	30
140	19	25	32
Increase/10 kpsi	1.3	1.8	2.3

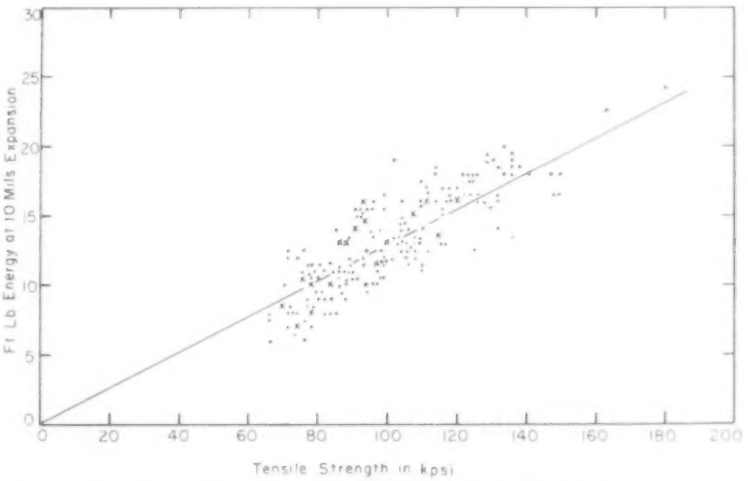

Fig. 5 Increase in energy absorption with tensile strength at constant lateral expansion (10 mils)

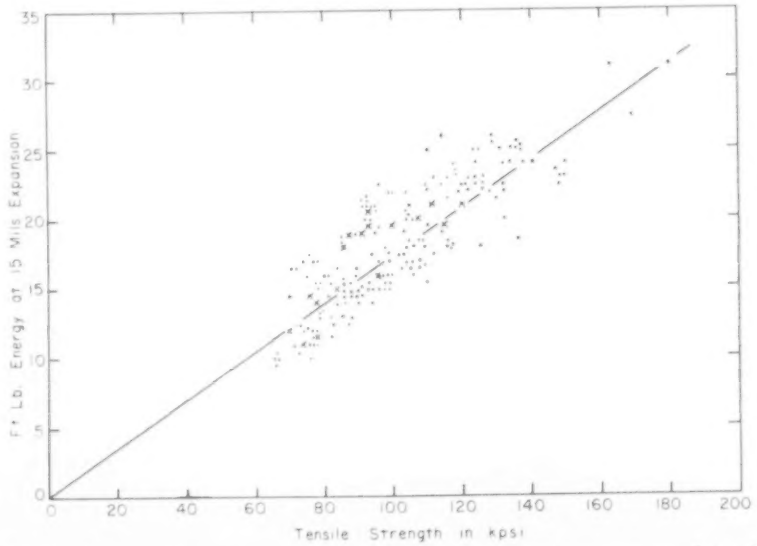

Fig. 6 Increase in energy absorption with tensile strength at constant lateral expansion (15 mils)

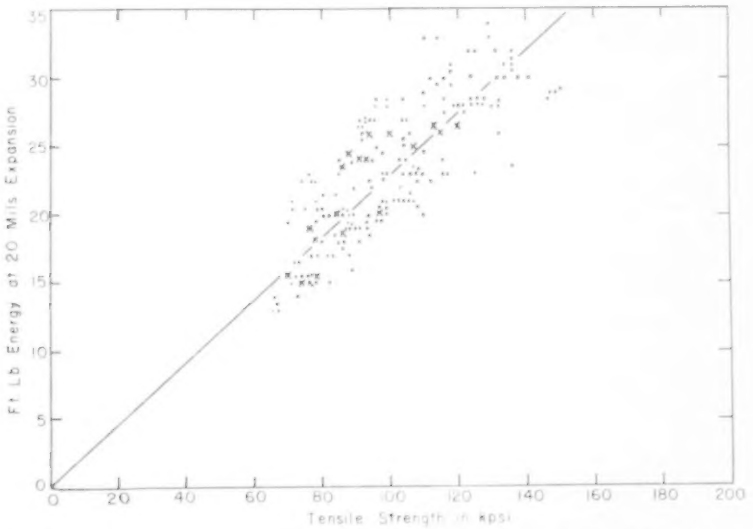

Fig. 7 Increase in energy absorption with tensile strength at constant lateral expansion (20 mils)

considered generally exhibited increasing tensile strengths.

The basic question is whether energy absorption or notch ductility is a better index of resistance to brittle fracture. A sliding scale of energy level to adjust for steel composition is justified if notch ductility is the critical property. Table 3 lists the increase in energy absorption with increasing tensile strength at lateral expansions of 10, 15 and 20 mils. The 15-mil lateral-expansion criterion suggests a variation in the energy-absorption criterion from 11 ft-lb at 60,000 psi to 25 ft-lb at 140,000-psi tensile strength.

It is not the intent of this report to verify this premise since it can be established only by direct service correlation. However, experimental evidence from various laboratories tends to confirm this observation. Under these circumstances it would be considerably simpler to measure the notch ductility directly and determine the transition temperature from the lateral expansion-testing temperature curve rather than to correct the criterion to be applied to the energy-temperature curve. Moreover, the measurement of lateral expansion appears to be more reproducible than energy absorption. The energy absorption is the product of an average force and deformation and therefore susceptible to the statistical vagaries of two variables, whereas lateral expansion is dependent only upon the deformation. The force factor of energy absorption is influenced by the manner in which the specimen passes through the supports, slight displacements of the Charpy bar in the jig, and other testing-machine variables.

General Discussion

The validity of a notch-ductility criterion, such as the lateral expansion in the Charpy V-notch test, ultimately must be established by correlation with service. However, further study of its general characteristics and relation to other tests should provide valuable information. The following aspects are currently under investigation.

Lateral expansion and the NDT generally correlate with an increased energy absorption for other than rimmed and semikilled steels. Preliminary studies have indicated approximately direct relation between the transition temperature of V-notch Charpy tests at the 10-mil lateral expansion and NDT in drop-weight tests.

Scatter in energy absorption-tensile strength curves (Figs. 5, 6 and 7) was observed to decrease noticeably when individual steels and particular microstructures within a given steel were plotted separately. This secondary effect of composition and structure may be revealed more sensitively by notch-ductility measurements than by energy values.

The energy absorption-lateral expansion curves (Fig. 3) are characterized by an intercept value and slope which are approximately proportional to the yield strength and tensile strength, respectively. The useful implications of these relationships require further study.

Summary

The results of this study can be summarized as follows:

1. The ductility component of energy absorption in the V-notch Charpy test can be evaluated by measuring the lateral expansion produced during deformation at the side of the specimen opposite the notch.

2. If notch ductility is accepted as the property critical to resistance to brittle failure, the energy level chosen as a criterion for transition temperature must be corrected for the tensile strength of the steel involved.

3. For the same notch ductility, a steel at 120,000-psi tensile strength will absorb twice the energy of a steel of 60,000-psi strength. At 15-mil expansion, for example, the energies are 21 and 11 ft-lb, respectively.

4. Lateral expansion is so readily measured that it could conveniently be specified directly as a criterion in place of a variable level of energy absorption dependent on the steel type.

5. The tendency of the Charpy test to correlate with service failures and with other laboratory tests at higher levels of energy in killed and low-alloy steels rather than in rimmed and semikilled ship steels is partially accounted for by this study of the effect of tensile strength on energy absorption.

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DISCUSSION BY C. E. HARTBOWER AND G. M. ORNER

Messrs. Gross and Stout have presented an interesting paper in which they hypothesize that the transition temperature of any steel may be associated with essentially one value of lateral expansion. The fact that the 15-ft-lb energy level is not applicable for many fully killed plain-carbon steels and for low-alloy high-strength steels points up the need for a less empirical criterion that can be applied to the V-notch Charpy test. Therefore, the authors have proposed a ductility measurement (lateral expansion) in preference to an energy measurement in the Charpy test.

The observation that "energy-expansion curves are characterized by an intercept value and slope which are approximately proportional to the yield strength and tensile strength, respectively," requires some qualification. This observation is important to the authors' argument because, unless there are significant differences in the energy-deformation relationship between steels, there is no advantage in a 15-mil expansion criterion over a 15-ft-lb energy criterion. Consider the energy-expansion plots obtained from plain-carbon steels as reported in the paper entitled "Poisson Effect in the Charpy Test."[1] Data from 15 pearlitic steels, for all practical purposes, fell on a straight line of essentially constant slope. The steels involved a variety of metallurgical variables including welding (tests involved heat-affected zone), grain-size variations (ASTM 3 to 8), deoxidation practice (aluminum killed, silicon killed and rimmed), aging (quenched from 1200° F and aged 1 and 30 days at 70° F, and furnace cooled from 1200° F and aged 30 days at 70° F) and chemical composition (carbon from 0.04 to 0.45% and manganese from 0.43 to 1.05% with hardness ranging from 60 to 86 Rockwell B).

On the basis of the above tests it was concluded that in pearlitic steel the energy-expansion relationship is largely independent of such metallurgical variables as chemical composition and heat treatment. Other pearlitic steels have been investigated since then; the data have all scattered closely about the same straight line. With regard to the paper under discussion, it is noted that the data presented in Fig. 3 for ASTM A-302-B heat treated to an ultimate tensile strength of 94 kpsi (x) fall on the line for pearlitic steel. The discussors would be interested in seeing the energy-expansion plots for Steels B and C of Fig. 1, Steel A212-B of Fig. 2, and Steel A285 of Fig. 4, as well as the microstructure of each of the above steels.

The discussors are of the opinion that separation of the crack-initiation and crack-propagation stages of fracture permits a more fundamental definition of transition temperature. If the deformation to initiate cracking were the same for all steels, then the use of a single level of lateral expansion would be justified. Experimentally, it has been observed that both the energy to initiate cracking and the attending lateral expansion vary considerably from steel to steel. Table 1 is presented for purposes of comparison, listing transition temperatures for the various steels under investigation by the discussors in recent months. Column (a) lists the low-blow transition temperatures, which are considered by the discussors to approximate closely the temperatures at which brittle fracture may be expected to occur in service. Separation of the crack-initiation and crack-propagation stages is accomplished by an easily executed variation in the standard technique for Charpy impact testing.[2] The procedure requires initiation of a crack by means of a low-energy blow and then propagation of the crack by a second full-capacity blow of the impact machine pendulum. Lateral expansion attending the initial blow provides a measure of the plastic-deformation work done in initiating the crack, and the difference between the lateral-expansion measurements taken before and after the fracturing blow provides a measure of the work done in propagating the crack. The transition temperatures so obtained are believed to be fundamental for the following reasons:

1. Low-blow transition-temperature determinations are based on a fundamental concept, viz., that one may differentiate between ductile and brittle fracture by noting the manner in which the intiating crack is propagated—a brittle fracture is propagated by continuous release of the elastic-stress field surrounding the crack, whereas a ductile fracture requires plastic-deformation work to extend the crack.

2. When either lateral expansion or energy associated with crack propagation is plotted against testing temperature, there is an abrupt change of slope in the low-temperature region of the transition curve indicating a sudden arrest in the rate of decrease of work required for crack propagation. The resulting inflection point is believed to occur at the temperature at which the plastic-deformation work required to propagate the crack in the center portion of the test specimen is zero; the plastic-deformation work occurring at and below the inflection point is believed to represent the work required to propagate the crack through the biaxially-stressed sides and bottom of the test specimen where the plastic constraint is insufficient for cleavage. Thus, the temperature corresponding to the inflection point in the transition curve is considered to be the maximum tem-

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The opinions or assertions contained herein are those of the authors and are not to be construed as official or reflecting the views of the Department of the Army.

Table 1

Material	Hardness	Microstructure	Initiation Energy	Initiation Expansion	Transition temperature (a)	Transition temperature (b)	Transition temperature (c)	Transition temperature (d)
AISI 4340*	Rc 27	Martensitic	30	15	−120	−150	−120	−115
	Rc 34	Martensitic	20	8	−110	−120	−120	−90
	Rc 45	Martensitic	13	4	+ 25	+120	0	
Nickel Steel†	Rb 82	Pearlitic	12	12	− 80	− 70	− 90	− 80
Class 90‡	Rb 99	Martensitic	30	19	− 80	−135	−100	−110
Class B§	Rb 83	Pearlitic	19	19	0	+ 5	0	− 5

* See Reference 2.
† See Reference 3 (0.14C, 1.50Mn, 3.3Ni).
‡ See Reference 4 (0.17C, 0.33Mn, 2.43Ni, 0.97Cr, 0.22Mo).
§ See Reference 4 (0.20C, 1.31Mn, 0.17Cu).

(a) Based on the concept of a "self-propagating" crack
(b) Based on an arbitrary 20 ft-lb energy level
(c) Based on the energy required to initiate cracking
(d) Based on 15-mil lateral expansion

perature at which a self-propagating crack can be initiated in a cross section of infinite dimensions.[3]

3. Charpy bars of four cross sections (standard depth-half width, full width and double width; and half depth-double width) and three notch types (standard Charpy V-notch, Charpy keyhole notch and half depth V-notch) have been investigated. The inflection points occurred at the same temperature for all notch and specimen geometries. Thus, the tests show the low-blow transition temperature to be independent of notch and specimen geometry within the limits of notch acuity and specimen size investigated. Moreover, the strain hardening and adiabatic temperature rise associated with the crack-initiation stage of fracture have little or no effect on the low-blow transition temperature.[3,4]

Column (b) of Table 1 lists transition temperatures based on an arbitrary energy level of 20-ft lb. Note in comparing columns (a) and (b) that there are discrepancies. When the energy level was adjusted to correspond to the energy required to initiate cracking (column (c)), the discrepancies were generally less serious. Note also that where discrepancies persisted, the transition temperatures listed in column (c) were lower than those obtained by the low-blow technique. Based on data from sub-size and keyhole-notched bars which indicated even lower transition temperatures using the crack-initiation-energy level, it was concluded that the discrepancies stemmed largely from adiabatic temperature-rise effects. In other words, in cases where a considerable amount of plastic deformation precedes crack initiation, the conventional transition curve as obtained by a single full-capacity blow indicates fictitiously low temperatures at any given energy level. The low-blow technique avoids the complication of adiabatic temperature rise because the specimen is recooled after the crack-initiating blow (consequently, the low-blow transition temperatures for keyhole and V-notched Charpy bars are the same). When 15 mils of lateral expansion were used (column (d)), a serious discrepancy occurred in the case of the AISI 4340 steel quenched-and-tempered to R$_C$ 45, viz., 15 mils exceeded the maximum lateral expansion developed at the highest temperature of test (+160° C). In the case of the pearlitic steels, the 15-mil transition temperatures were somewhat below the 20-ft lb transitions, as would be expected, since 15 ft-lb (15 mils) is less than 20 ft-lb. Likewise, the 15-mil transition temperature for the AISI 4340 R$_C$ 27 steel closely checked the transition temperatures of column (a) and column (c), because 15 mils corresponded to 30 ft-lb, the crack-initiating energy. In the case of the R$_C$ 34 material, 15 mils again corresponded to 30 ft-lb (Fig. D-1 herewith) and, consequently, the 15-mil transition temperature was higher than the transition temperature corresponding to 20 ft-lb (the crack-initiating energy level). From these and other comparisons that can be made using Table 1 and Fig. D-1, it would appear that there is little advantage in a 15-mil criterion over a fixed energy level.

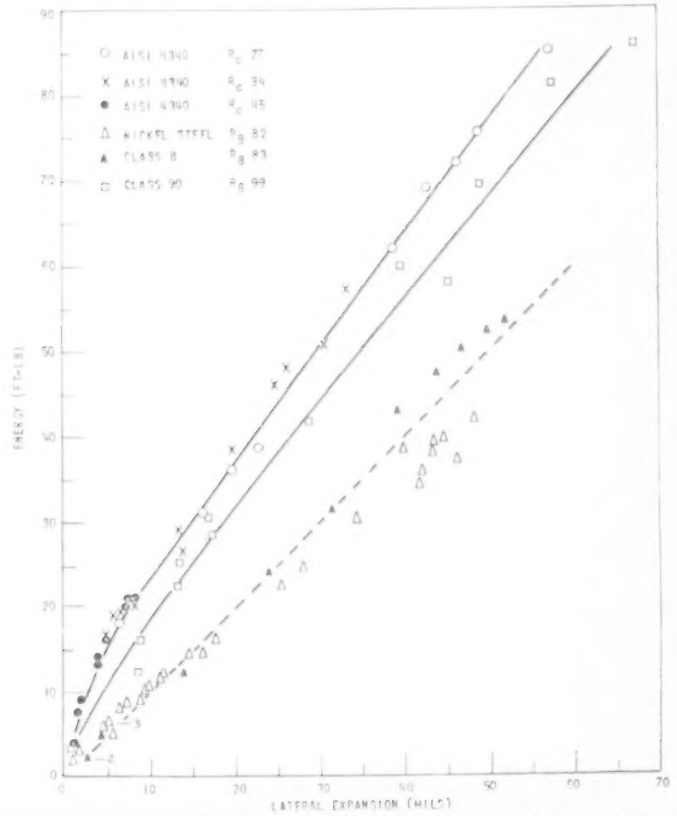

Fig. D-1: Energy-expansion relationships in pearlitic and martensitic steels. Note that the data for AISI 4340 are from one heat of steel quenched-and-tempered to three strength levels—and yet the overlapping of data indicate a common curve

In closing, the discussors would like to comment in connection with the authors' observation that "lateral-expansion values can be simply, rapidly and reproducibly determined with an ordinary micrometer calibrated in thousandths of an inch." Experience at Watertown Arsenal Laboratories does not support this observation, although it is agreed that lateral expansion can be more easily and reproducibly measured than maximum lateral contraction. Lateral expansion is now measured at Watertown Arsenal Laboratories by means of a special instrument featuring a dial indicator. Comparisons between measurements obtained with this fixture and standard flat-anvil micrometers indicated that lateral-expansion measurements made on fractured bars with a micrometer were not sufficiently reproducible. The reason for the lack of reproducibility is that the fracture seldom passes through the exact center of the expanded portion of the specimen and, frequently, the point of maximum expansion on one side of the specimen is located in one half of the fractured bar, while the point of maximum expansion on the opposite side is contained in the other half of the bar. In such a case, the lateral expansion as measured by a flat-anvil micrometer in each half of the test specimen is less than the true maximum width. By means of a dial-gage pointer and parallel-ground knife edges, this source of inaccuracy is avoided. The lateral expansion on each side of each half of the test specimen is measured separately; thus, the sum of the higher values from each side represent total lateral expansion.

References

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3. Orner, G. M., and Hartbower, C. E., "Effect of Specimen Geometry on Charpy Low-Blow Transition Temperature," *Ibid.*, 36(12), Research Suppl., 521-s (1957).
4. Orner, G. M., "The Effect of Notch and Specimen Geometry on Charpy Low-Blow Transition Temperature—Part II," WAL Report 178.87-8.

DISCUSSION BY NORMAN BLOCK

The concept of variant toughness levels as criteria for different strength levels is one that has gained increasing acceptance in recent years. The development of a method to establish the correlation between energy absorption and brittle-behavior susceptibility has been effectively accomplished in the correlation work conducted by Pellini and Puzak. A need has existed, however, for a more practical method of evaluation which would not require a series of correlation tests for each class of steel.

The authors have suggested an ingenious "common denominator" which could represent an extremely useful tool in evaluating susceptibility to brittle fracture. If additional correlations with other materials continue to substantiate those reported in the authors' paper, a significant contribution will have been rendered.

The authors' reference to the difficulties of lateral-contraction measurements is readily understood. The difficulty has been attributed to inconsistencies in locating the measuring device at precisely the same depth below the tension surface on every specimen. If such is the case, measurements taken on a device similar to a surface comparator should reduce much of the scatter which has been observed.

This discussor would like to suggest that the scatter observed in lateral-contraction studies is inherent in the fracture mechanism. The authors' data suggest that the scatter may be due to a sensitivity of crack initiation to minor variations in notch geometry. The variations in notch acuity iron out once the crack has been initiated. The acuity of the notch is then constant during propagation. Have the authors obtained data which might help to check the suggested explanation for the erratic results in lateral-contraction measurements?

Fracture occurring in an impact bar generally does not proceed completely through the bar in the brittle mode. A shear lip often appears on the compression side of the specimen, resulting from final separation in tension. It is to be expected that this final tension failure will be characterized by some lateral necking down at the lip. This necking phenomenon would have a subtractive effect on the lateral-expansion measurement. Would the authors comment on the effect of the shear lip, and indicate the magnitude of the error?

The authors are to be commended for giving us the results of this excellent work. It is hoped that additional investigations will continue to substantiate their results.

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AUTHORS' CLOSURE

The authors appreciate the comments of the various discussors, particularly since they emphasize certain critical areas which will require further study in order to provide completely satisfactory answers.

Messrs. Hartbower and Orner suggest that the variation in energy absorption at a given lateral expansion is primarily a function of microstructure and essentially independent of the strength, at least over the range of 62 Rb to 86 Rb (approximately 50,000 to 80,000 psi tensile strength) for ferrite-pearlite aggregates. In Fig. A of authors' closure the authors have presented energy-lateral expansion data over a wide range of strengths and embracing widely divergent microstructures. For simple ferrite-pearlite aggregates in plain carbon steels, the widest range of tensile strengths for which information was available is shown in the curves labeled A and B. The effect of strength in increasing energy absorption at all levels of lateral expansion is quite pronounced. The microstructure corresponding to B is given in Fig. 7—As Cooled-Oil, p. 166-s of this same issue in the paper entitled "Effect of Heat Treatment on the Microstructure and Low-Temperature Properties of Pressure-Vessel Steels."[1] The microstructure of A would be quite similar to the As Cooled-Foil in the same figure. Both microstructures are distinctly ferrite-pearlite aggregates, although the oil quenching has decreased the amount and grain size of the pro-eutectoid ferrite while increasing the amount of pearlite. Curve C-D

Code	Steel	Microstructure	YS-ksi	TS-ksi	Elong-%
A - □	A-201	Ferrite-Pearlite	28.7	56.4	36.0
B - ▲	A-212	" "	69.0	92.8	28.5
C - ×	A-302	Ferrite-Carbide	100.	149.	13.6
D - ○	T-1	Tempered Martensite[a]	150.	150.	14.2
E - ●	T-1	Tempered Martensite	126.	131.	19.5

[a] Strain-aged after tempering

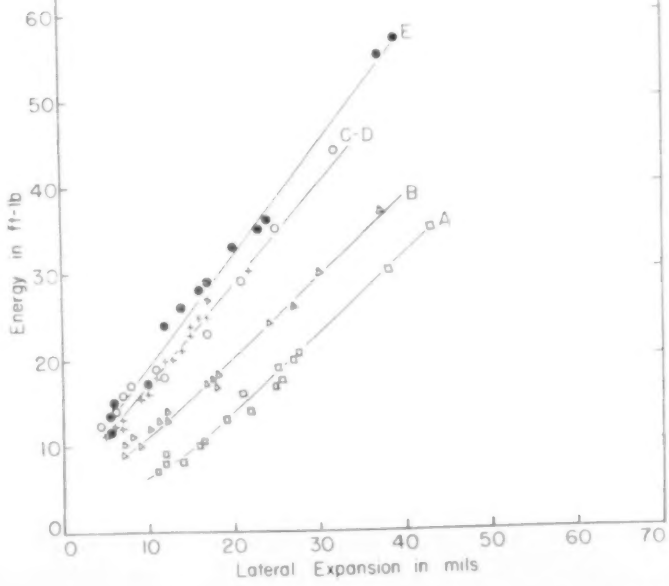

Fig. A. The effect of tensile strength on the relationship between energy absorption and lateral expansion for various microstructures

demonstrates the similarity that can occur when distinctly different microstructures exhibit similar tensile strengths. Material C has a tensile strength of 149,000 psi and its microstructure is given in Fig. 8—As Cooled-Oil of Reference 1. Material D is tempered martensite in the strain-aged condition with a tensile strength of 150,000 psi and a microstructure similar to that of Fig. 9—As Cooled and Stress Relieved-Oil. At the same strength level no observable difference in the energy-lateral expansion characteristics can be noted. On the other hand, Material E which has been treated exactly as D except for the absence of strain-aging, exhibits higher energy-absorption characteristics than D, although its tensile strength is lower. The authors agree with the observation that the type of microstructure exerts an influence beyond that of strength, and have stated this as a partial explanation of the scatter observed in Figs. 5, 6 and 7 of the paper. In fact, from the comparison of D and E there appear to be variables in addition to the basic microstructure which exert an influence. To date, however, all of the conditions of testing have produced results within the scatter reported.

Messrs. Hartbower and Orner show in their Fig. D-1 the effect of microstructure on the energy-lateral expansion characteristics. This effect cannot be isolated since the strength rises as the microstructure changes from a ferrite-pearlite aggregate to a martensitic structure. Therefore, the increased energy absorption of the martensitic structure may result from the increased strength rather than the change in microstructure. Moreover, if microstructure were the only controlling variable, the martensitic Class 90 curve would be expected to coincide with the AISI 4340 curves. A comparison of the energy absorption at 15 mils from this figure with that predicted from Fig. 6 of the authors' paper indicates substantial agreement as shown in Table 1 herewith.

The authors are more gratified than disturbed by the agreement between the "self-propagating" crack criterion and the 15-mil lateral expansion criterion as presented by Messrs. Hartbower and Orner in their Table 1. Where comparison is possible, agreement within 20° F results in all but one case where the difference is 30° F. The authors believe that an invariant criterion capable of predicting transition temperature within 20° F over a wide strength and temperature range merits serious consideration. In the case of the AISI 4340 (●) with a strength of approximately 212,000 psi, at which level the notch ductility in the fully fibrous condition is only 10-mil lateral expansion, it is doubtful if this material possesses sufficient inherent ductility regardless of its mode of deformation to be safely considered as a true structural material. Thus a suitable lateral-expansion criterion may eliminate materials lacking adequate ductility for critical service applications even though the consequence of failure may not be of the catastrophic brittle type. Table 1 also suggests the use of the 15-mil lateral expansion criterion rather than one of several other expansion values that might be chosen, providing the "self-propagating" crack criterion is related to service as suggested.

Table 1—Comparison of Energy Absorption at 15-Mil Lateral Expansion

Steel	*Microstructure*	*Hardness*	*Tensile strength, ksi*	*Energy at 15-mil lateral expansion* Hartbower, ft-lb	*Energy at 15-mil lateral expansion* Gross and Stout, ft-lb
AISI 4340 (X)	Martensitic	R_c34	159	30	28
AISI 4340 (○)	Martensitic	R_c27	130	29	23
Class 90 (□)	Martensitic	R_b89	115	25	21
Class B (▲)	Pearlitic	R_b83	76	15	14
Ni steel (△)	Pearlitic	R_b82	75	15	14

The advantage of a lateral-expansion criterion over an energy criterion is demonstrated in Table 3 of Reference 1 where differences in transition temperature as great as 130° F between the 15-ft lb and 15-mil lateral-expansion criteria are noted. The 20-ft lb transition temperatures reported in the discussors' Table 1 compare least favorably with transition temperatures determined by the other criteria. However, in each instance better agreement would result if an energy corresponding to 15-mil lateral expansion were employed.

The use of a special instrument to determine lateral expansion may improve the accuracy of measurement. The authors were concerned with the development of a technique which was simple and required no special apparatus. The use of a "tensioned" micrometer is also helpful in reproducing the pressure exerted during measurement. In the range of principal interest (10-20 mil), the expansion does not involve the formation of large shear lips. Under these circumstances the problem of "lip splitting" between the two halves of the specimen is not critical, and satisfactory values are obtainable with ordinary micrometers.

Mr. Block's observations regarding tension "tearing" on the extreme compression side are confirmed by examination of failed specimens. However, the point where final shear tearing occurs is displaced laterally from the point of contact with the tup. That is to say that failure of the last fibers occurs in tension but slightly to either side of the point of maximum compression. At this point the tension stress reduces the total contraction as suggested. However, since this point is displaced from the maximum compression point, the maximum lateral expansion is unaffected. This observation may well explain why compression "ears" usually appear on the same half of the broken specimen.

The authors have no further explanation of scatter associated with lateral-contraction measurements. Studies in this area are being carried out to determine causes for scatter in the energy-deformation relations in an attempt to isolate the individual effects of the force and deformation factors.

Reference

1. Gross, J. H., Kotteamp, E. H., and Stout R. D. "Effect of Heat Treatment on the Microstructure and Low-Temperature Properties of Pressure-Vessel Steels." THE WELDING JOURNAL, **37** (4), Research Suppl., 160-s to 168-s (1958).

EFFECT OF HEAT TREATMENT ON THE MICROSTRUCTURE AND LOW-TEMPERATURE PROPERTIES OF PRESSURE-VESSEL STEELS

Authors outline and discuss the effects produced by new heat-treating techniques presently employed on heavy-section pressure-vessel steels to improve their low-temperature properties

BY J. H. GROSS, E. H. KOTTCAMP AND R. D. STOUT

ABSTRACT. This paper describes the effects produced by new heat-treating techniques currently employed on heavy-section pressure-vessel steels to improve their low-temperature properties. Conventional normalizing treatments produce inferior notch toughness in plates of 2-4 in. and over because of the retarded cooling rate. Micro-structurally, this results in excessive ferrite grain and pearlite aggregate size in plain-carbon steels and increased amounts of higher-temperature transformation products in low-alloy high-strength steels. This problem is minimized by the use of liquid quenching. Quenching, in turn, produces a problem of variable cooling rate, microstructure and properties through the thickness of the plate.

Plates of seven low-alloy steels and two carbon steels were heat treated to reproduce the cooling rates at the surface and center of water-sprayed and of normalized 4-in. plate. It was found possible to improve the strength and particularly the notch toughness of the alloy steels by accelerated cooling, *provided* only that stress relieving followed the treatment.

FOREWORD. The authors gratefully acknowledge the financial support of the Pressure Vessel Research Committee of the Welding Research Council and the guidance of the various project subcommittees.

Introduction

In modern pressure-vessel applications the trend has been to increased working pressures over extended temperature extremes. Conventional plain-carbon structural steels can meet the pressure requirements only in heavy sections. The problems associated with increased section size have made higher-strength steels attractive. The number of potentially useful steels for pressure-vessel construction was revealed by a survey conducted by the Pressure Vessel Research Committee.[1] In many instances, however, little or no information was available on the mechanical properties and weldability of these steels. Several investigations[2,3] were sponsored to evaluate the suitability of representative steels in strength levels ranging in yield strength from 50,000 to 90,000 psi minimum and in tensile strength from 70,000 to 120,000 psi. Some of these steels derive their high strength from precipitation-hardening reactions and accelerated cooling to produce high-strength micro-constituents. Information on fabrication and service performance of these newer steels was insufficient and laboratory tests were conducted to assess high- and low-temperature mechanical properties and suitability to various fabrication operations. In general the results were encouraging. Some of these steels have received code approval and are in use today.

Almost as soon as information was obtained on plate thicknesses up to 1½ in., applications arose requiring substantial increases in plate thicknesses in the higher-strength steels as well as carbon steels. Investigation[4] of representative carbon and high-strength steels in 4 in. thickness again produced encouraging results. At the moment it is difficult to predict the ultimate thickness requirements of pressure-vessel applications.

The widening in operating temperature extremes has been accompanied by

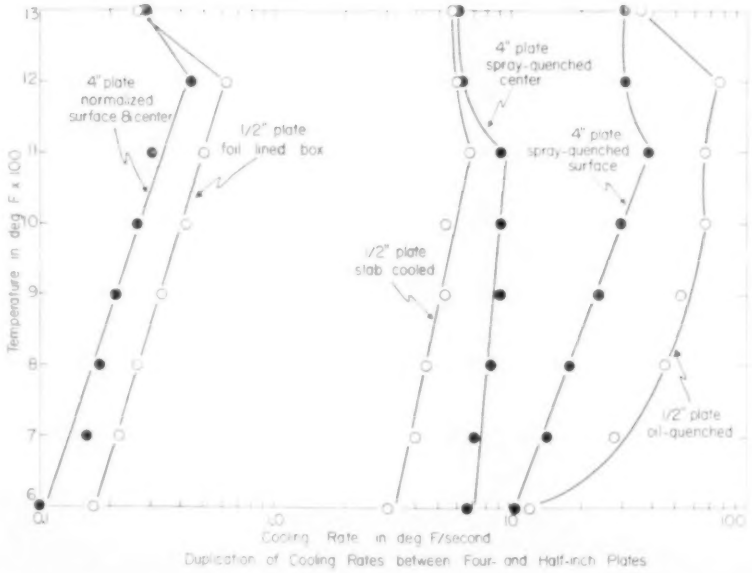
4" plate normalized surface & center
1/2" plate foil lined box
4" plate spray-quenched center
4" plate spray-quenched surface
1/2" plate slab cooled
1/2" plate oil-quenched
Temperature in deg F x 100
Cooling Rate in deg F/second
Duplication of Cooling Rates between Four- and Half-inch Plates

Fig. 1 Comparison of cooling rates in ½-in. plates treated to duplicate spray-quenched and normalized 4-in. plates

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Paper to be presented at the 1958 AWS Annual Spring Meeting to be held in St. Louis, Mo., April 14th to 18th.

corresponding increases in notch-toughness requirements. The necessity for adequate resistance to brittle fracture in low-temperature applications such as liquid gas storage is apparent. However, the need for exceptional notch toughness in elevated-temperature operation is not so obvious. This need arises from the unknown effects on notch toughness that may be introduced as a consequence of long-time elevated-temperature exposure, particularly when superimposed on various fabrication operations. Treatments designed to produce high-strength levels in heavy sections may result in microstructures which are particularly susceptible to embrittlement. In the nuclear-reactor field the possible detrimental effect of irradiation has led to stringent notch-toughness specifications to minimize susceptibility to brittle fracture during shut-downs.

Resistance to brittle fracture is dependent to large degree on the microstructure of the steel. In the case of plain-carbon steels with low hardenability, little can be done to change the basic character of the microstructure. However, excessive ferrite grain growth occurring during normalizing of heavy sections can be minimized by increased cooling rates such as spray quenching, and the notch toughness can be correspondingly improved. The higher-strength steels with substantial alloy content and increased hardenability likewise require increased rates of quenching in heavy sections to preserve the microstructures favoring good notch toughness. As thickness increases, alloy content cannot generally be increased to insure a uniform microstructure throughout the thickness. Thus, the types of heat treatment in use today result in a wide range of microstructures depending upon plate thickness, hardenability and severity of cooling. The basic mechanical properties of these diverse microstructures, as well as their response to various fabrication operations and service conditions, is relatively unknown. The necessity for such information was recognized by the Pressure Vessel Research Committee and recently described by Carpenter and Floyd.[3]

This report presents the results of the first phase of a study designed to provide detailed information on this subject.

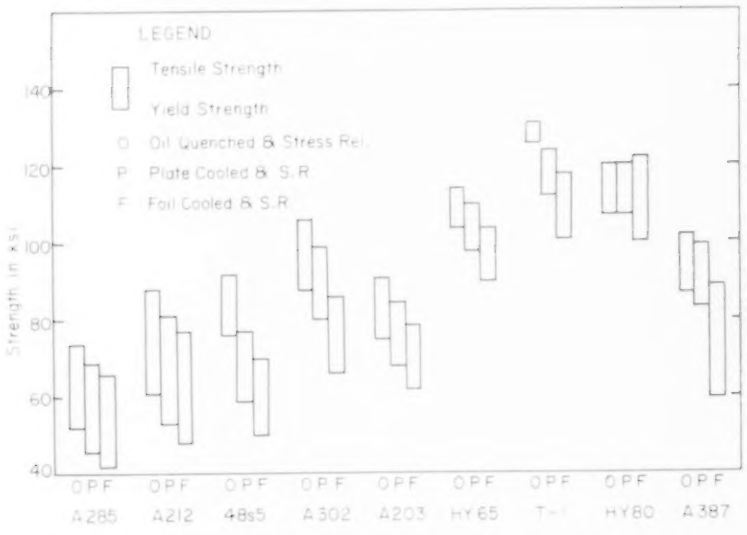

Fig. 2 Yield and tensile strengths obtained in pressure-vessel steels by various cooling methods followed by thermal stress relief

Experimental Procedure

The initial task in the investigation was to develop heat treatments which would simulate typical thermal cycles which are imposed on heavy sections. It was decided to duplicate the cooling rates for (*a*) a normalized 4-in. thick plate, (*b*) the surface of a 4-in. plate spray-quenched and (*c*) the center of a 4-in. plate spray-quenched. Instead of treating full sections, which would be prohibitively expensive, ½-in. plates were prepared by splitting 1-in. rolled plates from which tension, impact and

Table I—Chemical Analyses and Heat-Treating Temperatures

Steel	*Grade**	*C*	*Mn*	*P*	*S*	*Si*	*Ni*	*Cr*	*Mo*	*V*	*Ti*	*Cu*	*B*
ASTM A-285	C	0.20	0.53	0.020	0.016								
18s5	HT	0.15	1.09	0.033	0.028	0.18				0.09	0.009		
ASTM A-212	B	0.28	0.70	0.010	0.021	0.24							
ASTM A-203	D	0.15	0.64	0.010	0.026	0.22	3.64						
HY-65		0.12	0.48	0.013	0.032	0.21	2.16		0.39			0.70	
ASTM A-302	B	0.20	1.32	0.022	0.030	0.25			0.42				
ASTM A-387	D	0.09	0.44	0.013	0.011	0.25		2.18	0.96				
T-1		0.15	0.93	0.015	0.022	0.27	0.80	0.48	0.44	0.06			0.0031
HY-80	High	0.15	0.28	0.016	0.015	0.19	2.86	1.72	0.50				

Steel	*Austenitizing temperature, °F*	*Stress-relieving or tempering temperature, °F*
A-285	1650	1150
18s5	1650	1150
A-212	1650	1150
A-203	1650	1150
HY-65	1750	1200
A-302	1650	1150
A-387	1700	1350
T-1	1700	1200
HY-80 (Oil and plate)	1575	1150
HY-80 (Foil)	1650	1150

* All steels were firebox quality where applicable.

metallographic specimens could conveniently be obtained.

Cooling rates were measured on $\frac{1}{2}$-in. plates by affixed thermocouples under quenching conditions ranging from oil quenching to furnace cooling. Similarly, actual 4-in. plates were normalized and spray-quenched to obtain the basic cooling conditions which were to be matched. Largely by trial and error, satisfactory equivalent treating cycles were established as follows:

½-in. condition	*4-in. plate cooling*
(*a*) Normalized	(*a*) Cooled in foil-lined box
(*b*) Center of spray-quenched section	(*b*) Cooled between heavy steel plates
(*c*) Surface of spray-quenched section	(*c*) Still-oil quenched

The extent to which the cooling rates were duplicated is shown in Fig. 1. Actually an exact match is not necessary, since it was intended only to cover broadly the range of cooling rates which can be expected in the treatment of heavy sections of pressure-vessel steels.

Each steel was subjected to a series of heat treatments and mechanical treatments to simulate the operations that can be expected to occur in the fabrication of heavy-section pressure vessels. In this paper, the treatments cover essentially the series of cooling rates from the austenitizing temperature, reheating to the recommended tempering or stress-relieving temperature, and 5% tensile prestrain to represent cold forming. Tensile tests and V-notch Charpy tests were conducted on the steels after each operation. Further treatments now in progress include repeated and extended stress-relief treatments at the recommended temperature, long-time stress relief at lower temperatures, and short-time stress relief at higher temperatures. After prestraining, further aging at room temperature and at 500 and 700° F will be studied.

The schedule of treatments conducted thus far are as follows (not all steels were studied in all the conditions):

Austenitize (see Table 1 for temperature)

A. Cool in still oil
   1. Stress relieve (see Table 1)
   2. Stress relieve, prestrain 5% in tension, age 1 week at room temperature
   3. Stress relieve, prestrain 5%, stress relieve

B. Cool between heavy plates
   1. Stress relieve
   2. Stress relieve, prestrain 5%, age 1 week at room temperature
   3. Stress relieve, prestrain 5%, stress relieve

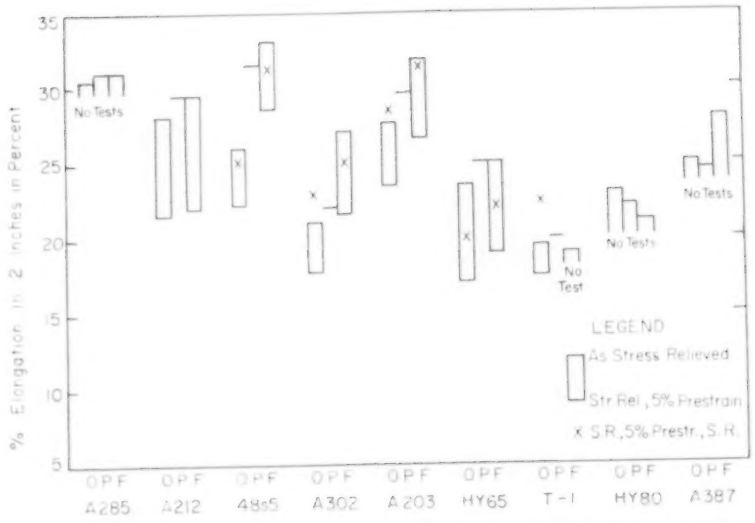

Fig. 3 Effect of 5% tensile prestrain and of subsequent thermal stress relief on tensile-elongation values of pressure-vessel steels cooled in still oil and in a foil-lined box, (equivalent to spray-quenched and normalized 4-in. plate, respectively)

B. Cool in foil-lined box
   1. Stress relieve
   2. Stress relieve, prestrain 5%, age 1 week at room temperature
   3. Stress relieve, prestrain 5%, stress relieve

Tests:

Half-size (0.252- x 1-in. gage length) tension tests at room temperature.

Charpy V-notch tests over suitable temperature ranges.

Standard end-quench tests on 1-in. diam bars.

Observations on the Charpy tests included the energy absorption, the lateral expansion at the face opposite the notch and the fraction of fibrous and crystalline fracture. The end-quench tests were included to furnish a convenient summary of the response of these pressure-vessel steels to a range of cooling rates.

Experimental Results

The chemical composition and the temperatures of heat treatment for each of the steels tested in this program are given in Table 1. A word of explanation

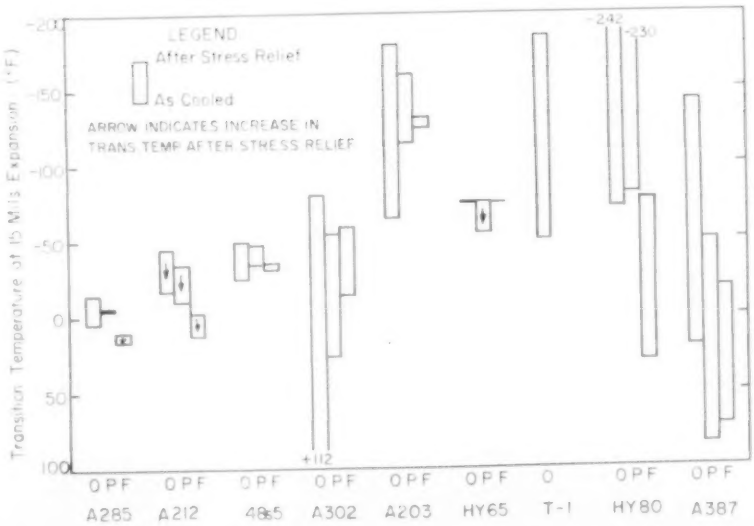

Fig. 4 Charpy V-notch transition temperatures of pressure-vessel steels as cooled in oil, between plates and in a foil-lined box in both as-cooled and thermally stress-relieved conditions. Note improvement by stress relieving

Table 2—Tensile Properties of Pressure-Vessel Steels

Condition	Yield stress, 0.2% ϵ, psi	Tensile strength, psi	Elongation, %	Reduction of area, %
ASTM A-285 steel				
As cooled				
Oil quenched	55,600	82,800	28	71.8
Plate cooled	47,700	72,300	32	67.2
Foil cooled	42,400	67,400	33	65.0
As stress relieved 1 hr, 1150° F				
Oil	51,600	74,100	30.5	71.4
Plate	46,000	71,000	31	68.7
Foil	42,000	66,200	31	67.0
ASTM A-212 steel				
As cooled				
Oil quenched	69,000	92,800	28.5	63.2
Plate cooled	59,200	85,600	29.5	62.0
Foil cooled	51,000	77,800	30.5	58.0
As stress relieved 1 hr, 1150° F				
Oil	60,700	87,800	28	66.8
Plate	53,400	81,600	29.5	60.8
Foil	48,700	77,200	29.5	57.4
Cooled, stress relieved, 5% prestrain				
Oil quenched	88,400	92,700	21.5	68.2
Foil cooled	71,200	82,400	22.0	59.2
18s5-HT steel				
As cooled				
Oil quenched	60,300	88,600	29.6	73.0
Plate cooled	58,200	75,400	32.0	73.1
Foil cooled	49,900	71,800	30.8	72.4
As stress relieved 1 hr, 1150° F				
Oil quenched	75,800	91,600	26	72.4
Plate cooled	59,200	76,800	31.5	73.7
Foil cooled	50,200	70,000	33	73.3
As cooled, stress relieved, 5% prestrain				
Oil quenched	91,600	96,400	22.2	72.4
Foil cooled	67,000	74,000	28.5	70.4
5% prestrain, stress relieved, 1150° F				
Oil quenched	86,200	96,200	25.1	73.0
Foil cooled	60,300	76,600	31.2	72.7
ASTM A-302 steel				
As cooled				
Oil quenched	100,000	149,000	13.6	49.0
Plate cooled	71,700	117,000	22.3	56.5
Foil cooled	54,800	94,200	23.8	56.0
As stress relieved 1 hr., 1150° F				
Oil	87,600	106,000	21.0	63.6
Plate	79,800	98,600	22.0	62.4
Foil	66,400	85,700	27.0	63.0
As cooled, stress relieved, 5% prestrain				
Oil	105,000	108,000	17.7	61.5
Foil	105,000	105,000	21.7	60.1
5% prestrain, stress relieved, 1150° F				
Oil	92,000	106,000	23	62.8
Foil	74,800	80,400	25	59.6
ASTM A-203 steel				
As cooled				
Oil quenched	84,200	132,000	20	55.0
Plate cooled	63,900	103,000	27.5	67.0
Foil cooled	59,200	83,800	29	63.8
As stress relieved 1 hr, 1150° F				
Oil	74,600	90,900	27.5	75.0
Plate	68,400	84,600	29.5	73.8
Foil	62,400	78,500	31.8	70.5
As cooled, stress relieved, 5% prestrain				
Oil	93,600	98,600	23.5	73.0
Foil	76,700	85,000	26.5	69.8
5% prestrain, stress relieved, 1150° F				
Oil	76,200	92,000	28.5	73.2
Foil	65,200	81,000	31.5	70.8
HY-65 steel				
As cooled				
Oil quenched	81,400	119,000	21.8	66.4
Plate cooled	70,300	104,000	25	66.9
Foil cooled	67,700	95,900	25	68.2
As stress relieved 1 hr, 1200° F				
Oil	104,000	114,000	23.5	71.4
Plate	97,800	110,000	25	71.2
Foil	90,100	103,000	25	70.1
As cooled, stress relieved, 5% prestrain				
Oil	129,000	129,000	17.1	68.3
Foil	110,000	110,000	19.3	69.0
5% prestrain, stress relieved, 1200° F				
Oil	124,000	125,000	20	68.7
Foil	105,000	110,000	22	69.6
T-1 steel				
As cooled (Oil quenched)				
As quenched	130,000	180,000	14.2	60.5
Stress relieved 1 hr, 1200° F	126,000	131,000	19.5	67.0
Quenched, stress relieved, 5% prestrain	135,000	136,000	17.6	66.1
5% prestrain, stress relieved, 1250° F	118,000	124,000	22.5	69.8
ASTM A-387 steel				
Oil quenched	120,000	163,000	17.5	69.6
Plate cooled	102,000	148,000	19	67.4
Foil cooled	56,600	109,000	23	58.2
Stress relieved 1 hr, 1350° F				
Oil	87,700	102,000	25	79.7
Plate	82,800	99,000	24.5	78.8
Foil	59,200	89,400	28	77.4
HY-80 steel				
Oil quenched	134,000	189,000	16	60.8
Plate cooled	122,000	177,000	16	61.1
Foil cooled	96,000	154,000	18	55.6
Stress relieved 1 hr, 1150° F				
Oil	107,000	120,000	23	73.0
Plate	107,000	120,000	22	74.8
Foil	100,000	128,000	21	65.2

Table 3—Notch Toughness of Pressure-Vessel Steels

Condition	15 ft-lb transition temperature, °F	15-mil lateral expansion transition temperature, °F	50% fibrous fracture transition temperature, °F
ASTM A-285 steel			
As cooled			
Oil	+ 14	+ 6	+ 64
Plate	+ 16	+ 4	+ 64
Foil	+ 26	+ 10	+ 80
As stress relieved 1 hr, 1150° F			
Oil	0	− 14	+ 60
Plate	+ 2	− 6	+ 64
Foil	+ 34	+ 16	+ 90
ASTM A-212 steel			
As cooled			
Oil	− 50	− 16	− 10
Plate	− 30	− 35	+ 28
Foil	+ 12	− 2	+ 58
As stress relieved 1 hr, 1150° F			
Oil	− 16	− 18	+ 35
Plate	− 6	− 10	+ 26
Foil	+ 22	+ 12	+ 68
Cooled, stress relieved, 5% prestrain			
Oil	+ 10	+ 6	+ 50
Foil	+ 52	+ 36	+ 84
18-5-HT steel			
As cooled			
Oil	− 32	− 26	+ 56
Plate	− 36	− 36	+ 30
Foil	− 24	− 32	+ 22
As stress relieved 1 hr, 1150° F			
Oil	− 56	− 50	+ 14
Plate	− 48	− 48	+ 30
Foil	− 36	− 36	+ 40
Cooled, stress relieved, 5% prestrain			
Oil	− 62	− 46	− 6
Foil	− 8	− 4	+ 26
5% prestrain, stress relieved, 1150° F			
Oil	− 46	− 34	+ 22
Foil	− 5	− 2	+ 60
ASTM A-302 steel			
As cooled			
Oil	+ 54	+ 112	+ 88
Plate	+ 16	+ 26	+ 63
Foil	− 12	− 16	+ 22
As stress relieved 1 hr, 1150° F			
Oil	− 85	− 70	− 60
Plate	− 60	− 55	− 36
Foil	− 60	− 60	− 22
Cooled, stress relieved, 5% prestrain			
Oil	− 44	− 40	− 28
Foil	− 6	− 6	+ 14
5% prestrain, stress relieved, 1150° F			
Oil	−110	−106	− 96
Foil	− 34	− 35	− 8
ASTM A-203 steel			
As cooled			
Oil	−105	− 66	− 20
Plate	−126	−115	− 34
Foil	−128	−124	− 48
As stress relieved 1 hr, 1150° F			
Oil	−205	−180	− 94
Plate	−170	−160	− 70
Foil	−130	−130	− 38
Cooled, stress relieved, 5% prestrain			
Oil	−198	−172	− 90
Foil	−106	− 98	− 34
5% prestrain, stress relieved, 1150° F			
Oil	−202	−188	−122
Foil	−122	−130	− 48
HY-65 steel			
As cooled			
Oil	−118	− 76	+ 10
Plate	− 96	− 76	+ 30
Foil	− 96	− 74	+ 40
As stress relieved 1 hr, 1200° F			
Oil	− 96	− 74	+ 40
Plate	−100	− 56	+ 32
Foil	− 92	− 74	+ 46
Cooled, stress relieved, 5% prestrain			
Oil	− 56	+ 26	+ 64
Foil	− 42	− 12	+ 52
5% prestrain, stress relieved, 1200° F			
Oil	− 98	− 26	0
Foil	− 44	− 30	+ 52
T-1 steel			
As oil quenched	−230	− 50	− 55
As stress relieved 1 hr, 1200° F	−225	−185	− 80
Quenched, stress relieved, 5% prestrain	−170	−100	− 68
5% prestrain, stress relieved, 1200° F	−204	−140	− 98
ASTM A-387 steel			
As cooled			
Oil	− 86	+ 20	+ 58
Plate	+ 56	+ 86	+104
Foil	+ 58	+ 72	+ 86
As stress relieved 1 hr, 1350° F			
Oil	−168	−142	+108
Plate	− 56	− 50	+ 8
Foil	− 20	− 18	+ 22
HY-80 steel			
As cooled			
Oil	−250	− 70	− 60
Plate	−250	− 80	− 60
Foil	− 15	+ 30	+100
As stress relieved 1 hr, 1150° F			
Oil	−270	−242	−175
Plate	−275	−230	−165
Foil	−140	− 76	+ 42

is necessary concerning the use of the term, stress relieving. The reheating operations following quenching, forming or welding are given various names. Generally after quenching, reheating is called tempering, while after forming or welding it is called stress relieving. Since in pressure-vessel fabrication, stress relieving is most commonly used to indicate reheating, that term has been adopted in this investigation of steels for pressure vessels. The reader may wish to substitute mentally "tempering" where it is more appropriate.

The mechanical test results are listed fully in Tables 2 and 3. Table 2 contains the results of the tension tests. Table 3 lists the transition temperatures obtained by three criteria: (1) at 15 ft-lb energy absorption, (2) at 15-mil lateral expansion and (3) at 50% fibrous fracture.

The authors wish to emphasize one point about the results reported here. The tables contain data for individual heats of each steel grade. While these steels all meet the grade specifications, their performance in these tests should not be used as an index of the characteristics of other heats in the same grade classifications. These tests were conducted primarily to reveal the variations in performance that result from changes in heat treatment and mechanical treatment. Thus, greater emphasis is to be placed on the relative effects of treatments for each steel rather than the absolute values of the mechanical properties reported.

Since the data in Tables 2 and 3 are cumbersome to analyze by inspection, summary graphs have been prepared to allow ready comparison. In Fig. 2, the yield and tensile strengths of heat-treated and stress-relieved samples of each steel are shown. Figure 3 presents elongation values after stress relief, after prestrain and after prestrain and stress relief. In Fig. 3, the plate-cooled series was tested only as stress relieved. The Charpy test results for as-cooled and as stress-relieved specimens are given in Fig. 4. Figure 5 indicates the effect of prestraining and prestraining followed by stress relief on each steel treated in oil or cooled in the foil-lined box.

The end-quench behavior of the steels is shown in Fig. 6. Two vertical lines are positioned in the graph to indicate the location in the end-quench bar having respectively the same cooling rate as the oil quenching and the plate cooling of the 1/2-in. plates.

Micrographs are available for each of the cooling rates imposed on the steels, both as-cooled and after stress relief. In Figs. 7, 8 and 9, microstructures are shown for a carbon steel, A-212, a 50,000-yield-strength steel, A-302, and a more highly alloyed steel, HY-80.

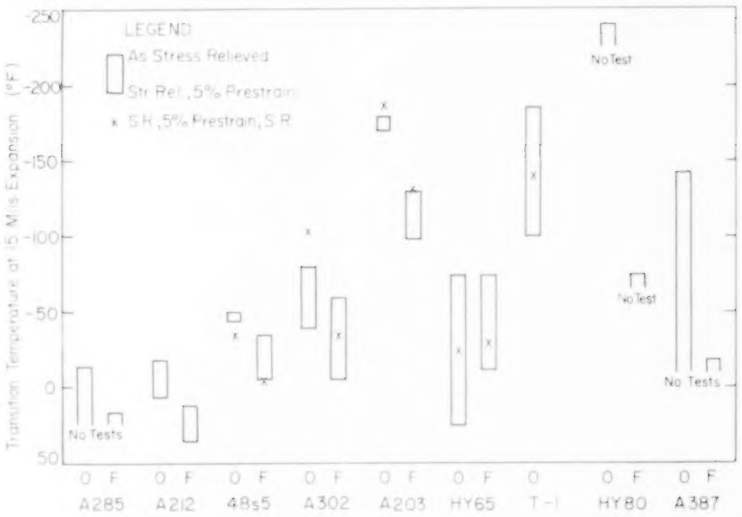

Fig. 5 Effect of 5% prestrain and of subsequent thermal stress relief on Charpy V-notch transition temperatures of pressure-vessel steels cooled in oil and in a foil-lined box, (equivalent to spray-quenched and normalized 4-in. plate, respectively)

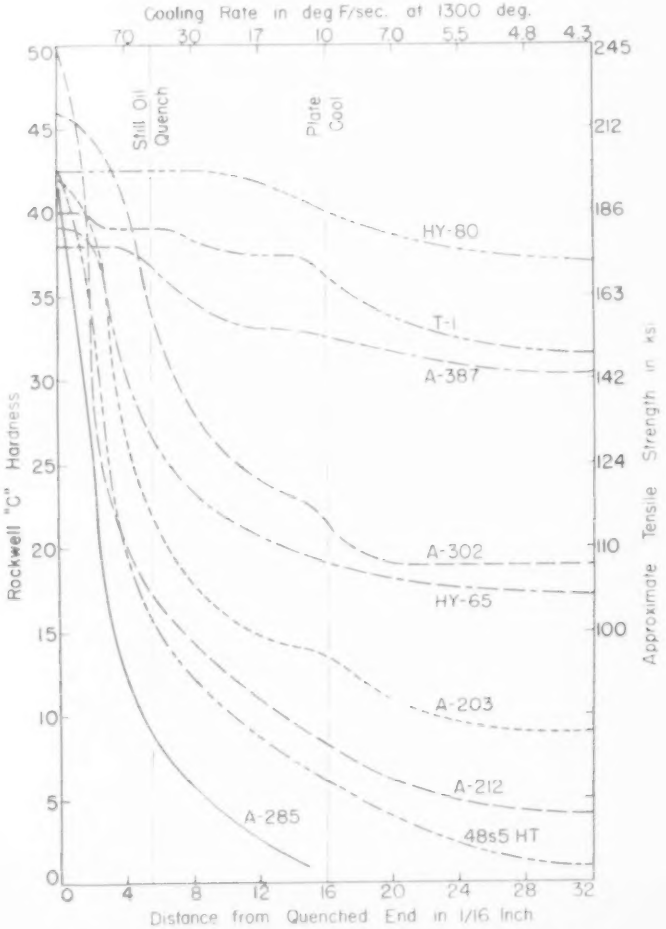

Fig. 6 End-quench characteristics of the pressure-vessel steels

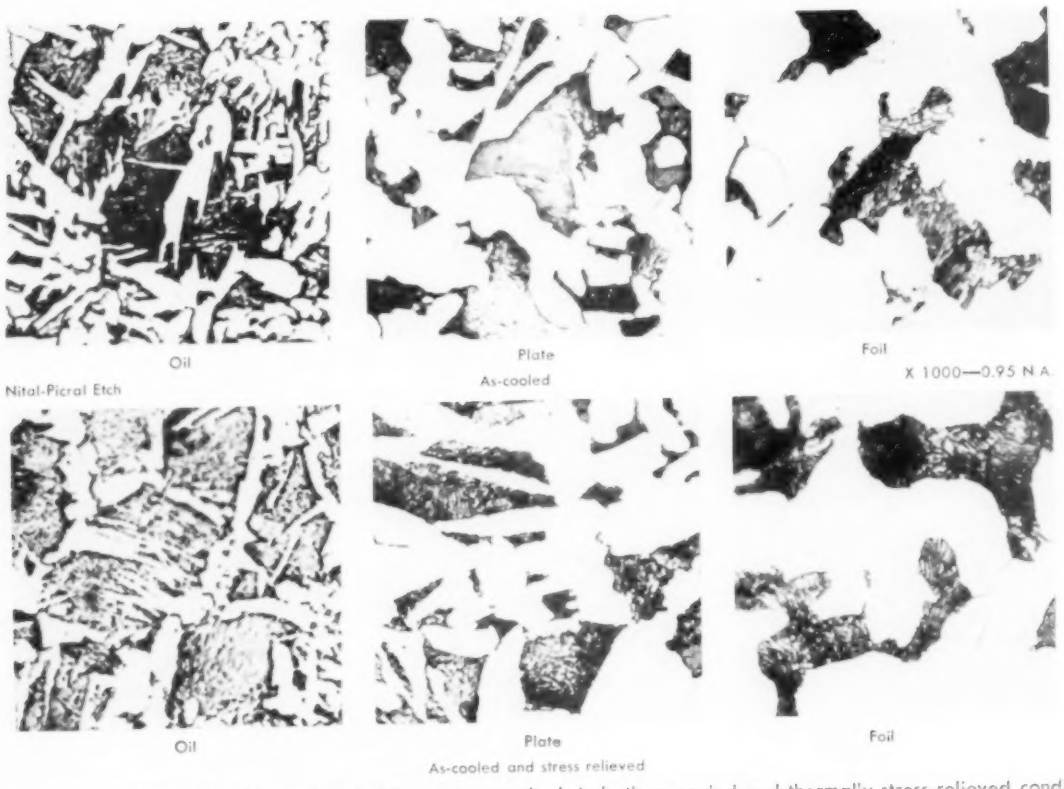

Fig. 7 Microstructures of A-212 steel cooled by various methods in both as-cooled and thermally stress-relieved conditions

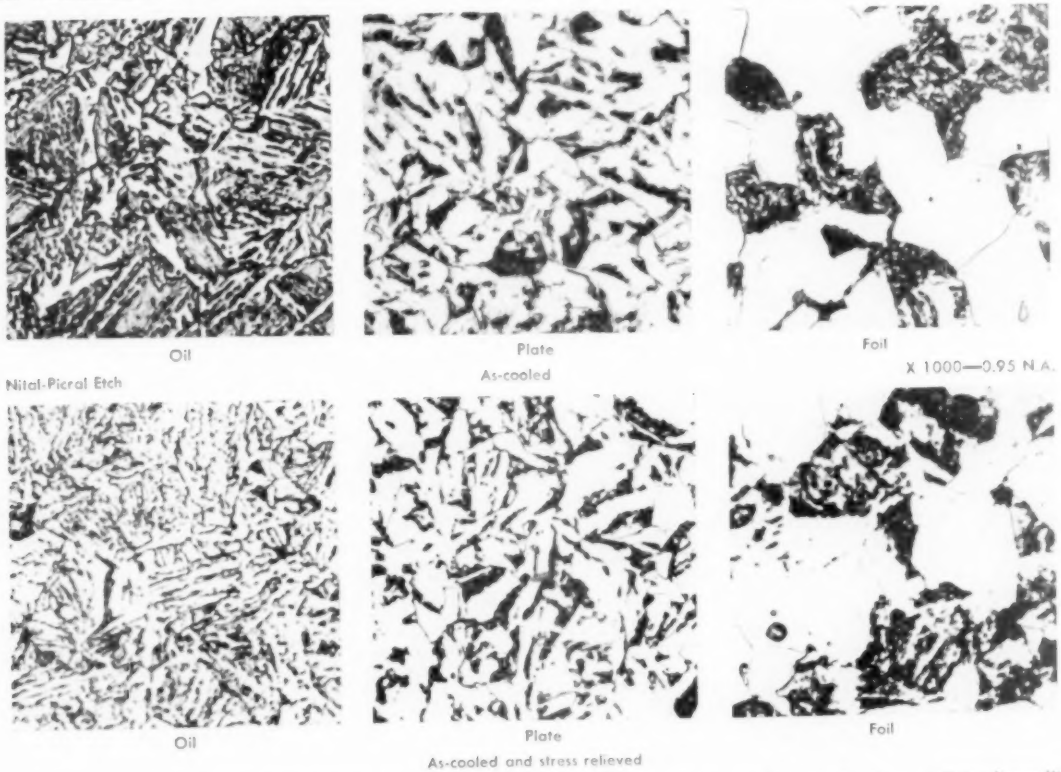

Fig. 8 Microstructures of A-302 steel cooled by various methods in both as-cooled and thermally stress-relieved conditions

Discussion

The basic question in the selection of materials for heavy-section pressure vessels is whether it is practical to choose combinations of steel compositions and heat treatments to provide the desired strength level and notch toughness at low temperatures. Accelerated cooling has already been utilized to improve the properties of heavy sections. It is worthwhile to examine the results reported here for confirmation of this method.

From Fig. 2, the gain in strength obtained from accelerated cooling and retained after stress relieving was noticeable. The alloy steels were strengthened considerably more than the carbon steels, as one would expect from their greater response to cooling rate shown in Fig. 6. The "yield-tensile" ratio generally was improved also by faster cooling.

As shown in Fig. 3, the tensile elongation dropped in value as strength was increased by faster cooling. The alloy steels changed more because their strength changed more. It cannot be stated whether this decrease in ductility is serious to service performance, but there is no reason to believe so. Prestraining lowered ductility roughly the 5% of elongation it used up. In all cases, stress relief after prestraining restored part or all of the elongation loss due to prestraining.

Broadly stated, the tension tests indicate strengthening is possible by accelerated cooling without serious loss of ductility. The alloy steels respond more markedly than do the carbon steels.

For low-temperature service, the gain in notch toughness possible by substituting alloy steels for carbon steels is well established. Figure 4 shows this trend despite the fact that these heats of carbon steel were somewhat better than can be expected on the average. Figures 2 and 4 show that strength and notch toughness can be enhanced simultaneously. Two facts stand out from examination of Fig. 4. First, stress relieving was *mandatory* for insuring a low transition temperature after accelerated cooling of the alloy steels. Second, after stress relief, the faster cooling provided marked improvement of notch ductility compared to foil cooling (equivalent to normalizing in a 4-in. section).

Figure 5 shows the loss in notch ductility induced by prestraining and 1 week room temperature aging. Stress relief after prestraining restored partially the loss in toughness except for one steel. While these data are too fragmentary to tell, in general the alloy steels show somewhat less sensitivity to strain aging than carbon steels.

The end-quench curves of Fig. 6 are interesting because they illustrate the necessity of alloy additions to obtain a useful response to accelerated cooling of heavy sections. None of the compositions studied was of sufficient hardenability to be hardened in a 4-in. section, nor does it seem likely that sufficient alloying would be feasible to produce full hardening in heavy-section pressure vessels. The point is that considerable improvement in low-temperature performance is available by accelerated cooling even though full hardening is not produced. As the micrographs of Figs. 7, 8 and 9 illustrate, the benefit of faster cooling can be traced to suppression of massive proeutectoid ferrite and the formation of stronger, more finely interspersed aggregates of ferrite and carbides. Stress relief is important because it softens and spheroidizes the areas of high hardness as originally cooled.

Summary

The results of this investigation can be summarized as follows:

1. Accelerated cooling could be used to increase the yield and tensile strengths of heavy-section steels, particularly if they contained moderate

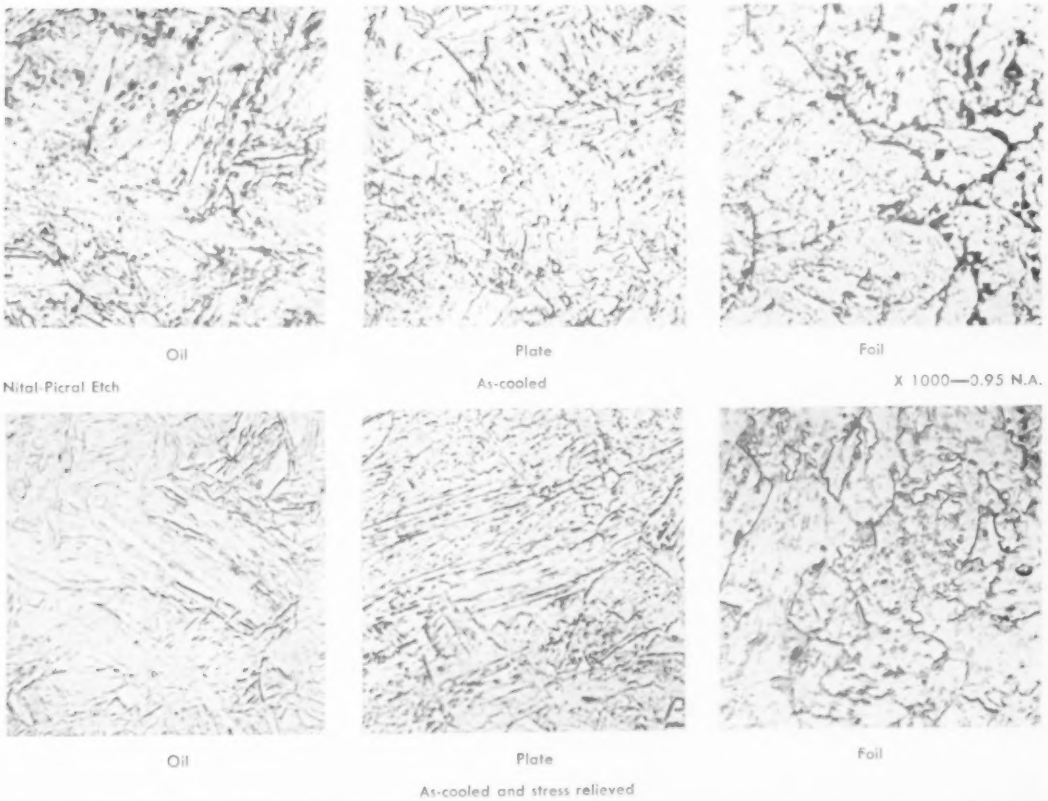

Fig. 9 Microstructures of HY-80 steel cooled by various methods in both as-cooled and thermally stress-relieved conditions

amounts of alloying elements.

2. Notch toughness required for low-temperature service was enhanced appreciably in low-alloy steels by accelerated cooling, provided only that stress relief is employed after cooling.

3. The benefit of accelerated cooling originated principally from the suppression of massive ferrite and the formation of finer aggregates of ferrite and carbide. Stress relief or tempering was essential to good toughness because it softened and spheroidized the hardened areas.

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HYDROGEN IN MILD STEEL WELDS

BY M. LEFÈVRE

Measurements were made of the hydrogen content of weld metal deposited by mild-steel covered electrodes. The hydrogen content was made up of diffusible hydrogen, evolved at 480° F for 4 to 5 hr in a mercury trough, and stable hydrogen evolved at 1200° F in vacuum.

Moisture in Coverings

Moisture in coverings was analyzed at 2200° F by the U.S. Navy method. Butt welds were made in ½-in. plates with 5/32-in. electrodes at normal currents. Only the first third of the electrode was used. The interpass temperature was 300° F, and the welds were cooled in water immediately after completion. Specimens were machined and placed in the mercury trough within an hour of completion of the welds. The results, Table 1, show that the weld metal becomes saturated at low moisture contents.

Table 1 — Effect of Moisture Content of Coating on Hydrogen Content of Weld Metal

Type of coating	*Moisture content of coating, %*	*Hydrogen content, ml per 100 g* *Diffusible*	*Stable*	*Total*
Neutral (6020)	1	10	4½	14½
Neutral (6020)	7½	11½	8	19½
Basic (low hydrogen)	0.15	1	0.2	1.2
Basic (low hydrogen)	1.3	4.5	1	5.5
Basic (low hydrogen)	8½	9	2.5	11.5

Humidity

Low-hydrogen electrodes dried 2 hr at 660° F were deposited at two humidities, Table 2. The weld metal contained the same hydrogen as if welded at normal humidity but with 0.25 and 0.50% moisture in the coating. A sevenfold increase in humidity had about the same effect in raising the hydrogen content of the weld metal as doubling the moisture content of the coating.

Table 2 — Effect of Humidity

Temperature, ° F	31	82
Relative humidity	60	75
Absolute humidity, grams of water per cubic meter of air	2.8	20
Moisture content of coating determined at 2200° F, %	0.28	0.26
Diffusible hydrogen, ml per 100 g	1.24	2.31
Stable hydrogen, ml per 100 g	0.26	0.32
Total hydrogen, ml per 100 g	1.50	2.63

Interpass Temperature

Three butt welds were made in 5/8-in. plates with 5/32-in. rutile-cellulose electrodes, 10 min per pass. After cooling 5 min in air, one weld was immersed in cold water, 54° F, the second was immersed in boiling water and the third was maintained at 570° F. The results in Table 3 show that 570° F lowers the hydrogen content, but that specifications requiring degassing at 390 to 570° F to avoid hydrogen effects do not accomplish their objective.

Table 3 — Effect of Interpass Temperature

Interpass temperature, ° F	*Hydrogen content, ml per 100 g* *Diffusible*	*Stable*	*Total*
54	8.8	16.1	24.9
212	8.1	15.4	23.5
570	3.7	3.1	6.8

Time Interval Between Passes

At 570° F interpass, three butts were prepared with the same rutile-cellulose electrode but with different intervals between passes, Table 4. In practical welding this is not an important factor, but for test welding where the interpass interval is 5 to 7 min, the variation in hydrogen content may be considerable.

Table 4 — Effect of Interpass Interval

Interval between passes, min	*Hydrogen content, ml per 100 g* *Diffusible*	*Stable*	*Total*
5	8.6	9.9	18.5
10	3.7	3.1	6.8
20	2.9	4.7	7.6

Degassing

Diffusion of hydrogen from weld metal was measured on cylinders ¾ in. diam, 2 in. long. About four days reduced the diffusible hydrogen to zero in neutral and rutile-cellulose weld metal. Heating to 480° F releases hydrogen more rapidly than at room temperature, but the same quantity is evolved. Stable hydrogen starts to evolve at 570° F, and no more is evolved above 1290° F.

Abstract of "La teneur en hydrogène des soudures d'acier doux en fonction de quelques conditions d'exécution," published in Revue de la Soudure, **13**, 189-191 (1957). The author is Technical Director of S.A. Arcos, Brussels. (Abstracted by Dr. G. E. Claussen.)

EFFECTS OF STEEL-MAKING PRACTICE ON SUBMERGED-ARC WELD POROSITY

Investigation undertaken to determine the effect of steel-making practice upon the weld-porosity susceptibility of nominally-similar materials used in fabricating pipe and pressure vessels

BY JAMES T. LAPSLEY, JR.

ABSTRACT. Weld-porosity susceptibility was investigated for 10 heats of nominally-similar low-carbon steel representing four open-hearth deoxidations: aluminum-silicon and silicon semikilled, and aluminum- and mechanically-capped practices. Processing variable effects of teeming sequence, ingot slab position and as-rolled sheet position were also included.

Submerged-arc welding was used with welding procedure standardized to accord with recommended industrial practice. Porosity evaluation was by radiograph interpreted against the ASME Boiler Code weld-porosity standards.

Results indicated significant variability in weld-porosity sensitivity among the steels, although the severity of such inherent porosity was less than that caused by inferior weld preparation.

Weld-porosity sensitivity appeared independent of deoxidation practice. Variation was not attributed to composition differences of O_2, C, S, Mn, Al, Si and P for which analyses were available.

Greatest differential porosity sensitivity in terms of processing parameters was associated with sheet position, interior-sheet-material welds being less susceptible than those from as-rolled sheet edges. A moderate teeming sequence effect was noted for semikilled steels which showed reduced pore-formation tendency with teeming sequence. Ingot slab position did not exert any consistent or marked effect on porosity occurrence.

Causes for the weld-porosity susceptibility variations exhibited among these steels were not isolated or ascertained.

Introduction

A vexing problem encountered in the fabrication of steel pipe and pressure vessels is the occurrence of open-void porosity or "leakers" in welded joints. Such defects are obviously serious, causing rejected product and expensive rework. The immediate remedy usually involves tightened inspection and modified welding procedure, frequently with reduced productivity.

Much of the production for these applications is from low-carbon open-hearth steel in gage or light-plate thicknesses. Commonly, material specifications are chemical only, usually carbon, sulphur and phosphorus. For production economy, fabrication typically favors automatic welding, simplified joint preparation and rapid rates of welding.

Occasionally, customer complaints claiming faulty steel as the cause of weld-porosity difficulties are directed to steel producers. Usually, field investigation of such complaints is difficult and the outcome indeterminate because of the large number of possible contributory sources of porosity which are present and over which control is lacking. In a few instances, however, an effective remedy seemingly has been obtained solely by changing the offending steel to an identical grade of steel but from a different heat or producer. In such instances, weld-porosity sensitivity would appear related to steel-making practice and thus possibly subject to improvement and control.

The present investigation was undertaken to determine the effect of steel-making practice upon the weld-porosity susceptibility of nominally similar materials used in fabricating pipe and pressure vessels. For steels of similar composition, the major material variable would appear to be deoxidation. A second variable would be that of possible segregation associated with mill practice, namely: (a) effect of teeming sequence, (b) ingot variations and (c) as-rolled sheet variations. Finally, variability in melting and mill procedures in processing nominally-identical heats of steel might be significant. In the study, all other sources possibly contributing to weld porosity were either eliminated or controlled by standardization.

Experiment Design

Low-carbon steel (0.15–0.20%) was chosen for study as being typical of materials used in fabricating pipe and pressure vessels. Four open-hearth deoxidation practices employed in producing steels of this nominal composition were investigated: aluminum-silicon semikilled, silicon semikilled, aluminum capped and mechanically capped. As a check on variability in production, three heats of each deoxidation practice were planned.

Segregation effects were investigated by sampling material from each heat as follows: (a) first, middle and last ingot of the teeming sequence; (b) top and bottom slabs cut from each ingot; (c) sheet interior and as-rolled edge position from each slab.

The relative susceptibility of the materials to pore formation during submerged-arc welding was determined by radiographic examination of welds made under standard conditions. The standard welding procedure employed was established so as to (a) be representative of welds used in pipe and pressure-vessel fabrication, (b) conform to recommended welding practices and (c) yield acceptable welds with respect to penetration, reinforcement, fusion and undercut at reasonably high rates of welding speed. Detailed information respecting the above variables is presented in the following section.

Experimental Equipment and Procedure

Weld Materials

The planned material program was not fully realized because of mill scheduling difficulties, cobble during rolling and loss of material identification. Only one heat of mechanically-capped steel was obtained so that no check on variability of this practice was possible. With respect to the study of segregation effects, complete positional variables were obtained for only four heats, fortunately representing each of the four deoxidation prac-

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Table 1—Test Program Material Presentation

Aluminum-Silicon Semikilled Steels

Steel A			Steel E				Steel F	
FTS&I	MTS&I	LTS&I	FTS&I	MTS&I	xxx	xxx	MTS&I	LTS&I
FBS&I	MBS&I	LBS&I	FBS&I	xxx	LBI	xxx	MBS&I	LBS&I

Silicon Semikilled Steels

Steel C			Steel G			Steel H		
FTS&I	MTS&I	LTS&I	FTS&I	xxx	LTS&I	FTS&I	MTS&I	xxx
FBS&I	MBS&I	LBS&I	FBS&I	MBS&I	LBS&I	FBS&I	MBS&I	xxx

Aluminum Capped Steels

Steel D			Steel J			Steel K		
FTS&I	MTS&I	LTS&I	FTS&I	MTS&I	LTS&I	xxx	xxx	LTS&I
FBS&I	MBS&I	LBS&I	FBS&I	MBS&I	xxx	xxx	MBS&I	LBS&I

Mechanically Capped Steels

Steel B	
FTS&I	FBS&I
MTS&I	MBS&I
LTS&I	LBS&I

tices. The additional heats, while only partially complete, still served effectively as a check upon heat variability.

Because of the large number of material variables present in the investigation, the following code designation has been employed throughout the report to permit ready recognition and interpretation of the test data. Teeming sequence is indicated by the designations "F," "M" and "L," the nominal first, middle and last ingot poured from a given heat. For each ingot, material from the top cut or slab is designated by "T" and the bottom cut by "B." Sheet position for each specimen is indicated by "I" for edges cut from the interior of the sheet and by "S" for as-rolled sheet or skelp edges. Thus, material from a middle ingot, top cut and sheet interior is designated "MTI." Table 1, utilizing the above designation, presents compactly the associated material variables represented in the investigation. Missing positional variables are indicated by "xxx."

Material for weld tests was obtained from $^3/_{16}$-in. hot-rolled sheet as strips 6 in. wide by 10 ft long, sheared lengthwise in the rolling direction. Except for variations incident to deoxidation practice difference, the steels were essentially of similar nominal composition. For the 97 material variables represented, carbon averaged 0.17% and ranged from 0.10 to 0.27%, sulphur averaged 0.034% with range 0.020 to 0.051%, and phosphorus ranged from 0.008 to 0.03% with mean of 0.015%.

Welding Technique

Standard welding conditions of joint design, edge preparation and welding materials and equipment were selected to represent typical good industrial practice. Within this reference, preliminary tests were made to establish detailed operating conditions yielding acceptable welds with respect to fusion, penetration, undercut and reinforcement while favoring relatively-high welding speed. The conditions so established were maintained constant for all subsequent tests evaluating material effects upon porosity. The welding conditions are described and discussed separately in the following sections.

Weld-Joint Design. A square-edge butt joint of the $^3/_{16}$-in. sheet was selected as being both simple and typical of practice in welding gage material. The joint edges were tightly butted without root separation and were clamped during welding.

Weld Preparation. Mill scale was cleaned from surfaces adjacent to weld edges by sandblasting manually using #20 grit. A two-inch strip on both surfaces of edges to be welded was cleaned so as to present a bright metal surface to visual inspection.

Edges to be welded were subsequently machined by face milling. From $^1/_8$ $^1/_4$ in. of metal was removed from sheet interior specimens in order to eliminate any mill scale broken into the edge during shearing. As-rolled sheet edges were also machined with sufficient metal removed to obtain a straight edge of full sheet thickness, typically $^1/_4$-$^1/_2$ in. Approximately one fifth of the as-rolled edges had been shear trimmed at the mill. Such specimens were also machined but the amount of material removed previously is not known.

The initial 10-ft material samples were torch cut to 40-in. lengths to permit machining and handling. The carbide cutter used for machining gave an excellent surface, approximating a ground finish, which aided inspection for possible sheet lamination.

Welding Equipment. Single-electrode, single-pass submerged-arc automatic welding using dc with reversed polarity was selected for the tests since such procedure is common industrially. Single-pass welding simplified interpretation of test results whereas automatic welding offered uniformity of weld conditions for the comparative evaluation of weld results.

A wide choice of excellent welding equipment of the desired type is commercially available and used industrially.

Welding current was obtained from two d-c generators of 375-amp rating operated in parallel. The light duty cycle and short welding time employed permitted satisfactory operation above nominal rating. A general view of the welding equipment used is shown in Fig. 1.

Weld Backing and Clamping. A water-cooled copper backing was used both to promote rapid weld cooling and to assure standard welding conditions. The backing consisted of two laminated $^1/_2$ x 4-in. copper plates with four $^1/_4$-in. diam copper tubes inserted in circular grooves, machined in the faying surfaces. Cooling water from a manifold was circulated through the tubes. The backing was grooved $^3/_8$ in. wide by $^1/_{32}$ in. deep beneath the weld joint to assure full penetration and to furnish added reinforcement.

Samples were aligned and clamped to the backing by strap clamps acting on strong backs to distribute forces. Clamps were of aluminum to eliminate arc-blow difficulties. An added transverse clamp at the free end of the weld kept the joint from opening during welding. Figure 2 presents a detailed view of the welding arrangement.

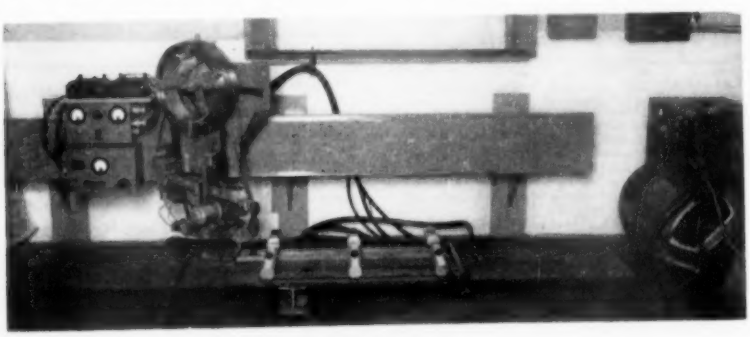

Fig. 1 General view of welding equipment

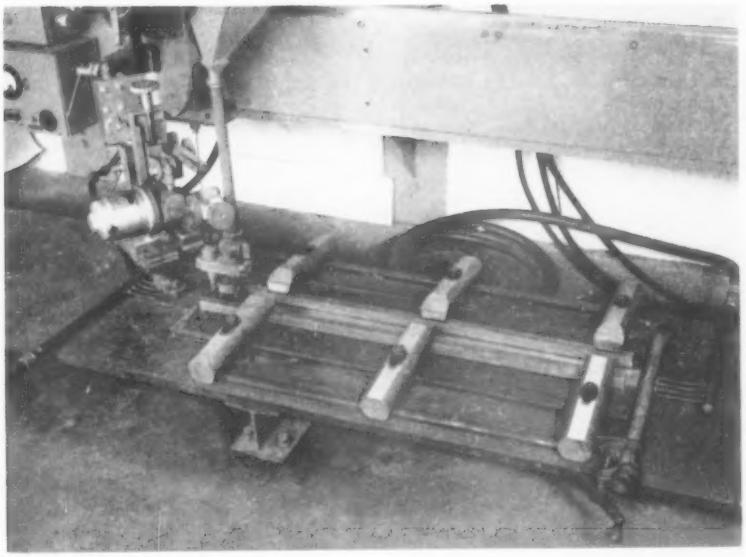

Fig. 2 Detailed view of welding setup

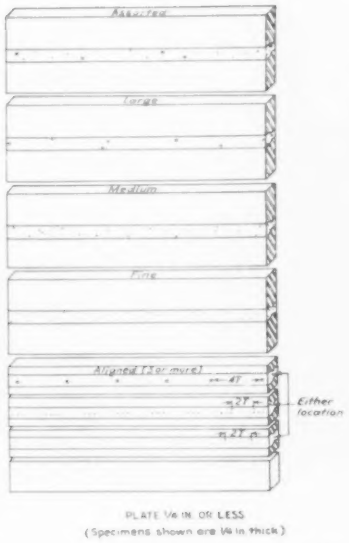

Fig. 3 ASME Boiler Code porosity chart showing limiting permissible weld porosity

Electrode and Flux. Electrode and flux of the same manufacture as the welding equipment were employed. The electrode selected for the program is recommended by the manufacturer for high-speed butt welds in gage and light-plate thickness mild steel. The rod, $\frac{1}{8}$ in. diam, was produced from killed steel with nominal composition: 0.13% C, 1.05% Mn, 0.32% Si, 0.03% S and P. Inquiry of the producer indicated that rod manufacture is closely controlled with chemical analysis by billets during production.

The flux selected is recommended by the manufacturer for use with the electrode employed and particularly for the production of sound, leakproof welds on material which, due to ineffective cleaning, may contain mill scale, oil or other surface residue. Flux was stored in a closed container with new flux used for each day's operations. During the day, flux was reused, being replenished with new flux as required. Flux was applied by gravity feed ahead of the weld to a depth of $\frac{3}{4}$ in., established by trial as sufficient to cover the arc and still vent gases freely.

Weld Voltage, Current and Speed. Preliminary tests were made to establish the standard welding conditions for use in the test program. Whereas primary interest related to weld soundness, acceptable welds with respect to penetration, fusion, undercut and reinforcement were also desired. Within these limitations and those of the equipment, the highest compatible welding speed was sought. The following condi-

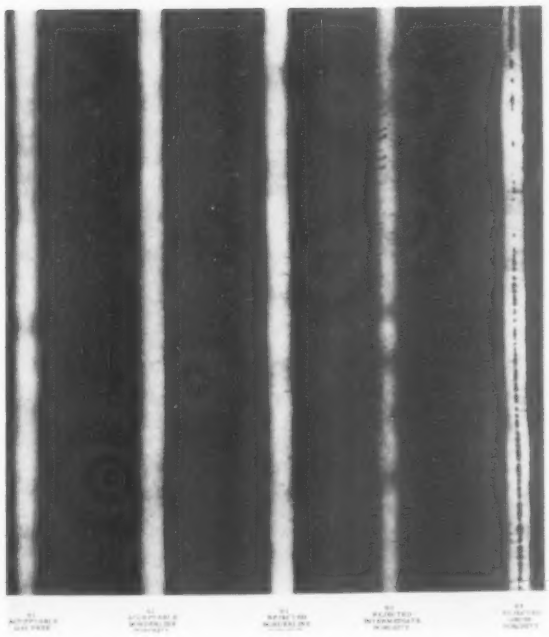

Fig. 4 Weld radiographs, graded weld-porosity standards

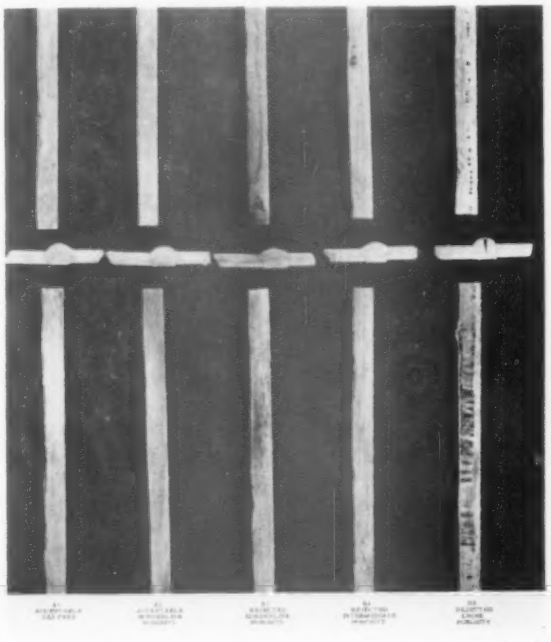

Fig. 5 Sectioned welds, graded weld-porosity standards

tions determined in this manner were established as standard for the study: welding speed, 60 ipm; voltage, 27 v; current, 800 amp.

Frequent calibrations of carriage speed during the program indicated less than ¼% variation. Laboratory-type instruments were used to measure voltage and current for each weld. Over the test program, voltage varied from 26 to 28 v and current ranged from 780 to 820 amp, about the nominal average values of 27 v and 800 amp. Although attempted, closer regulation of voltage and current was not achieved.

Reversed polarity was used with welding proceeding away from the ground terminal.

Porosity Determination

Samples for X-ray inspection approximately 12 in. long by 2 in. wide were torch cut from the test welds. The welds were about 36 in. in length and samples were taken from the last half of the weld so as to avoid transient starting and stopping conditions.

Radiographic inspection service was obtained from a commercial laboratory. A standardized X-ray exposure was used for all test samples which afforded sensitivity equal to ¾% of the weld material thickness as determined by penetrameter readings.

Films were interpreted for porosity in accordance with standards of the ASME Boiler and Pressure Vessel Code, Section VIII, Unfired Pressure Vessels, 1956 Edition. Appendix IV of this standard presents "Porosity Charts" showing permissible weld porosity for small, medium, large and mixed pore sizes and for permissible spacings for various sizes of aligned porosity. The chart applying to gage materials is reproduced as Fig. 3. Inspection results based on this standard were reported as "accepted" or "rejected."

Inasmuch as inspection to the Boiler Code standard permitted only an attribute comparison, the radiographs were re-evaluated for porosity in terms of a graded standard permitting interpretation of degree of porosity. The standard used was established by selecting five weld samples encompassing the range of porosity encountered in the tests. Two degrees of porosity rated "accepted" under the Boiler Code were established as "A1" and "A2," completely gas free and borderline acceptable, respectively. Three degrees of porosity rated "rejected" under the Boiler Code were established as "R1," "R2" and "R3," borderline rejected, intermediate, and gross porosity, respectively. The radiographs for the five reference standards are shown in Fig. 4. The same welds are presented in longitudinal and transverse section in Fig. 5 with top and bottom photographic views shown in Figs. 6 and 7. X-rays interpreted against this graded standard were reported in terms of the reference which they most closely approximated.

Oxygen Analysis of Weld Materials

Single determination oxygen analyses as determined by vacuum-fusion technique were obtained from a commercial laboratory. Analysis coupons taken from weld materials were located within ½ in. of edges subsequently welded.

Expense considerations limited the number of tests. Consequently, analyses from each heat were obtained for the middle ingot, top cut, sheet edge and interior positions where material was available. This sampling was selected as being most nearly representative of each heat. In addition, for each heat of the four deoxidation practices having complete positional variable representation, analyses for the bottom cut of the middle ingot were also obtained. Complete analyses for all 12 positional variables were obtained for Steel A, aluminum-silicon semikilled deoxidation.

Effect of Surface Preparation on Porosity Sensitivity

A supplementary investigation was made to determine the effect of variation in weld-joint preparation upon porosity because of its importance as a standardized variable in the main test program. These tests were restricted to Steel A of the study. Welds for each material variable of this steel were made for the following conditions of joint preparation: (a) sheared edges with mill scale, (b) machined edges with mill scale and (c) sheared edges, surfaces sandblasted. Except for these departures in surface preparation, the standard welding conditions used in the main investigation were followed, thus permitting comparison with results obtained for this material under the standard conditions of sandblasted and machined-edge preparation.

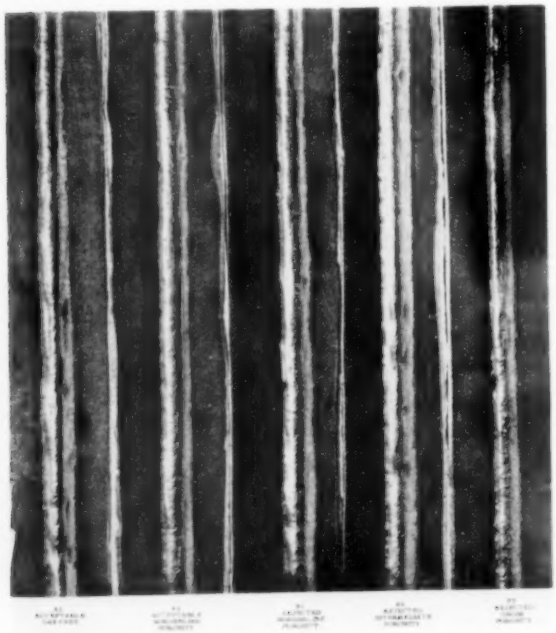

Fig. 6 Top view, welds for graded weld-porosity standards

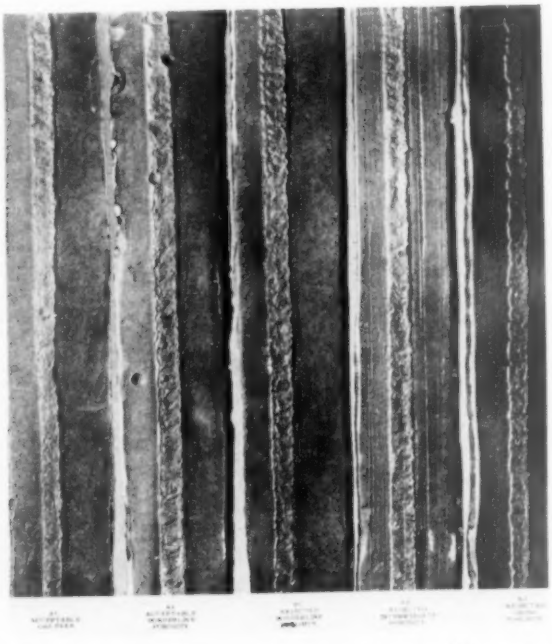

Fig. 7 Bottom view, welds for graded weld-porosity standards

Since welds from this special series of tests exhibited markedly-increased porosity, a special graded porosity standard was devised for use in their evaluation. Three radiographs encompassing the range of porosity encountered were selected as reference standards as shown in Fig. 8. These were designated "X1," "X2" and "X3" with X1 exhibiting least porosity, X3 extreme porosity, and X2 intermediate porosity. It should be noted that all three of these special reference standards would be rejected under the Boiler Code and that X1 corresponds approximately to R2-R3 (Fig. 4) of the graded porosity standard used for porosity evaluation for the main investigation.

Experimental Results

Weld-porosity test results for the major part of the investigation are reported in tabular form for each deoxidation practice in Tables 2 through 5. The first steel presented in each case is complete with respect to the 12 positional segregation variables of the test program with the additional steels listed being only partially complete. Only one heat of steel was available for evaluation of the mechanically-capped deoxidation practice, Steel B, Table 5.

The tabular presentation is arranged according to material location as designated previously in the discussion of the weld materials program, with main division in terms of interior and exterior sheet position and further subdivision according to teeming sequence and ingot position.

In order to emphasize the data distribution, a semigraphical presentation was used with individual test results indicated by "x's" in terms of the graded weld-porosity standards of Figs. 4 through 7. In this scale, A1 and A2 correspond to acceptable welds under the ASME Boiler Code weld-porosity standard, Fig. 3, and R1, R2 and R3 represent rejected welds of increasing degree of porosity.

Because of the varying number of tests made for the several material conditions, results have been reported also in terms of percent of welds made which proved defective, thus facilitating comparison of results. Results are so expressed in terms of two criteria, the ASME Boiler Code weld-porosity standard, Fig. 3, and a less severe standard in which rejection was on the basis of the more marked porosity exhibited by sample R2 of the graded weld-porosity standards, Figs. 4–7. The main effect of this latter standard is to accept the borderline porosity rejects of the Boiler Code. Comparison of the same test results in terms of both standards affords an index of the severity of the porosity present.

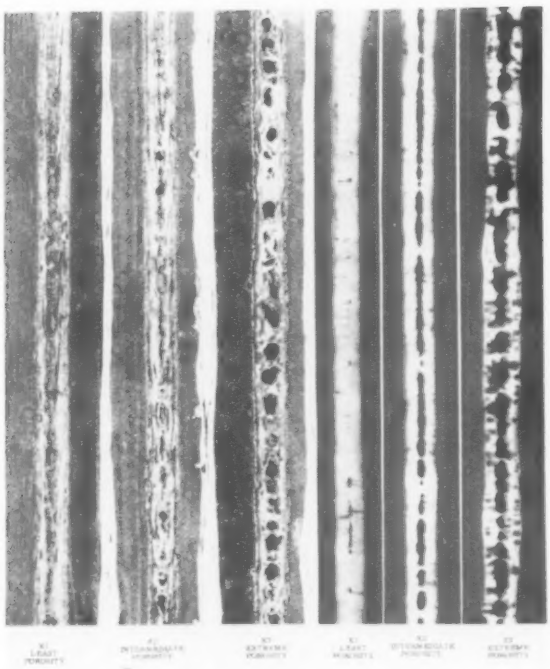

Fig. 8 Welds selected as standards for special tests evaluating the effect of surface preparation on weld porosity

Table 2—Weld-Porosity Test Results; Aluminum-Silicon Semikilled Steels

Material location	Oxygen, %	Carbon, %	Sulphur, %	Porosity rating A1	A2	R1	R2	R3	% Defective ASME	% Defective R2
				Steel A						
FTS	0.020	0.15	0.024	XXX		X	X		80	20
FBS	0.026	0.14	0.029			X	XX		100	67
MTS	0.015	0.15	0.033			XXX			100	0
MBS	0.015	0.15	0.031	XXXXX					0	0
LTS	0.024	0.15	0.030	XX	X	X	X		80	20
LBS	0.014	0.15	0.031	XXX	X				0	0
FTI	0.012	0.15	0.036		X	X		X	67	33
FBI	0.018	0.14	0.031	XXX	X				0	0
MTI	0.012	0.15	0.033	XXXX					0	0
MBI	0.016	0.14	0.028	XXXX	X				0	0
LTI	0.026	0.14	0.030	XXX	X				0	0
LBI	0.013	0.14	0.032	XX	XX				0	0
				Steel C						
FTS		0.17	0.034			XX	X		100	33
FBS		0.17	0.029		XX		X		33	33
MTS	0.065–0.052	0.12	0.034	XXX					0	0
FTI		0.17	0.030		X	X			50	0
FBI		0.16	0.032	XX	X				0	0
MTI	0.0075–0.0068	0.17	0.033	XX		X			33	0
LBI		0.17	0.031		X		X		50	50
				Steel F						
MTS	0.011	0.15	0.032				X	XX	100	100
MBS		0.15	0.031				XX	X	100	100
LTS		0.13	0.030		XX	X			33	0
LBS		0.17	0.031			X	XX		100	67
MTI	0.0094	0.18	0.031		X	XX			67	0
MBI		0.18	0.027			XX	X		100	33
LTI		0.20	0.032		XX	X			33	0
LBI		0.19	0.032			XX			100	0

Table 3—Weld-Porosity Test Results; Silicon Semikilled Steels

Material location	Oxygen, %	Carbon, %	Sulphur, %	Porosity rating A1	A2	R1	R2	R3	% Defective ASME	R2
Steel C										
FTS		0.20	0.041				XXXXX	X	100	100
FBS		0.18	0.038			X	X	XXXX	100	83
MTS	0.020	0.18	0.037			X	XXX		100	75
MBS	0.048	0.11	0.031				XXXXX		100	100
LTS		0.16	0.038			X	XXX		100	75
LBS		0.18	0.037				XXXX		100	100
FTI		0.19	0.038			XXX	X	X	100	40
FBI		0.19	0.040			XX	XXX		100	60
MTI	0.014	0.19	0.038		X		XXXX		80	80
MBI	0.014	0.20	0.039	X	X	XXXX			66	0
LTI		0.18	0.037		X	XXX			75	0
LBI		0.19	0.039	XX		X			33	0
Steel G										
FTS		0.16	0.035		XX			X	33	33
FBS		0.19	0.038				XXX		100	100
MBS	0.019	0.22	0.036				XX	X	100	100
LTS		0.17	0.037				XX	X	100	100
LBS		0.19	0.036				XX	X	100	100
FTI		0.27	0.037		XX			X	33	33
FBI		0.18	0.040		XXX				0	0
MBI	0.020	0.27	0.035		XXX				0	0
LTI		0.19	0.037	X	XX				0	0
LBI		0.20	0.037		XXX				0	0
Steel H										
FTS		0.13	0.040		X		XX		66	66
FBS		0.17	0.046	XX	X	X			25	0
MTS	0.0094	0.18	0.046		XXX				0	0
MBS		0.18	0.046	XX	XX				0	0
FTI		0.18	0.047		XXXX				0	0
FBI		0.17	0.045	XX	X				0	0
MTI	0.0088	0.18	0.046	XX	X				0	0
MBI		0.17	0.046	XXX	X				0	0

To assist evaluation and interpretation, analyses for carbon, sulphur and oxygen (where available) have been included for each material variable.

Table 6 presents results of the special series of test welds for Steel A made to evaluate the effect of weld preparation upon porosity. Because of markedly greater porosity in these welds, the special graded porosity standard of Fig. 8 was used for their evaluation. Weld-porosity results for these same material variables but with the standard weld preparation of the major test program (sandblasting and edge machining) are given in Table 2, Steel A. Results from the two tables are comparable if the two porosity standards used are correlated by noting that condition X1 (Fig. 8) of Table 6 corresponds approximately to R2-R3 (Fig. 4) of Table 2.

Table 7 presents the data of Tables 2–5, expressed as percent of welds defective under the two porosity criteria, in rearranged form in terms of the test program positional parameters of teeming sequence, ingot position and sheet position as well as for all welds made from each steel. Since only one steel of each deoxidation is complete with respect to all 12 positional variables of the test program, caution should be exercised in making comparison of results between steels. The partially complete steels have been indicated by asterisk with the degree of representation shown parenthetically as a percentage.

The total results for all welds made from each steel tested are presented compactly in Table 8 in terms of percent of welds defective under the two weld-porosity criteria. As in Table 7, relative completeness of positional variable representation is expressed in percent.

Discussion of Results

Test Program Appraisal

Inasmuch as standardization of test conditions other than the major program variables was an important element in the design of the investigation, the achievement of this goal is reviewed briefly prior to analysis of the test results. The major fixed variables included weld material composition, welding conditions and surface preparation.

Material Composition. Since the program assumed nominally-similar low-carbon steels of differing deoxidation practice, a statistical study was made of the composition variation present in the 97 coupon analyses for the 10 steels studied. The mean value, standard deviation and range for each element analyzed is shown in Table 9. In general, the 10 steels exhibit a reasonable degree of material uniformity. Manganese and phosphorus were quite uniform for all steels. Individual steels exhibited possibly significant differences in carbon and sulphur contents, while segregation was noted within steels as a function of positional variables. Aluminum and silicon were differentially present among the steels as would be anticipated from deoxidation practice differences. The variations noted are considered in detail in later discussion.

Welding Conditions. As stated in the procedure description, variation of 7% in voltage and 5% in current was experienced throughout the welding program. Such variations were erratic and did not show any trend, as with continuous welding; frequently higher voltage and current were associated but not consistently. Porosity effects, if any, from this cause should be essentially random.

Five coils of electrode and six 100-lb lots of flux were used during testing. Porosity effects from these sources could be consistent since many of the tests for a given material were run consecutively. Variability introduced here should be that associated with commercial uniformity of the two products.

Weld-Surface Preparation. Comparison of results from the special tests of variant weld-surface preparations, Table 6, with those obtained for the same material with standard test-program preparation, Steel A, Table 2, demonstrates clearly the adverse effect upon weld porosity of sub-standard weld preparation. Of the three special preparations, the sheared-edge-with-mill-scale condition gave greatest porosity. The two semi-improved procedures, machined-edges-with-mill-scale and sheared-edges-with-sandblasted surfaces, were essentially similar, exhibiting significantly reduced porosity although still markedly worse than obtained for the standard program practice of machined edges and sandblasted surfaces. Considered in terms of opportunity for contamination of the weld zone by surface oxides, these results appear logical and further indicate that for this steel, mechanically-included scale from sheared edges exerts an adverse effect on weld porosity of magnitude similar to that resulting from surface mill scale.

Examination of the results for Steel A, Table 2, also shows clearly an apparent material-position effect on weld porosity, reduced susceptibility of interior sheet material as contrasted with as-rolled sheet-edge material.

This effect is not noted in any of the results of Table 6, apparently masked by the greater effect of adverse surface preparation. It would thus appear that the porosity effects considered in the major part of the investigation are of lesser magnitude than those occasioned by these instances of sub-standard weld preparation.

Test Weld Variability. Cursory examination of the raw results shown in Tables 2-5 indicates a good degree of uniformity among the individual test welds made under nominally identical conditions. In general, the several tests for each condition correspond within one range increment of the porosity scale with greater scatter appearing only infrequently. It thus would appear that the test-program objective of variable standardization was attained practically except as qualified specifically in the preceding discussion.

Effect of Positional Variables

The sheet positional effect upon weld porosity previously noted in the discussion of edge-preparation effects can be observed also in varying degree in the other test materials, Tables 2-5. This effect is perhaps better examined in Table 7, especially arranged in terms of the test-program positional parameters of teeming sequence, ingot position and sheet position. Results are given as percent of welds defective for each positional grouping within each steel with defects determined by both the Boiler Code and the special graded porosity standards. Use of two standards permits some interpretation of porosity severity, that is, a steel exhibiting borderline porosity might be 100% defective under the Boiler Code yet completely acceptable under the second standard.

Since only one steel from each deoxidation practice was fully represented with respect to all positional variables of the test program, comparison of results for these materials with those from partially complete steels requires caution, noting particularly the degree of representation and what positional variables are lacking. The practice followed here makes major evaluations from complete steels, using results from the other steels to verify trends and assess variability where it is believed such comparisons have validity.

Effect of Teeming Sequence. Considering results for the first, middle and last ingot of each heat and deoxidation practice from Table 7, Steel A, aluminum-silicon semikilled, exhibits decreasing porosity sensitivity with teeming sequence. This trend appears verified by Steel F with Steel E probably non-valid for comparison because of inadequate representation.

Steel C, silicon semikilled, shows a similar though less-marked trend which is partially substantiated by Steel H with Steel G showing essentially no effect.

Of the aluminum-capped practice, Steel D shows the same trend only slightly while it is reversed for Steel J, being especially marked for the R2 standard evaluation. Steel K would appear to be indeterminate because of missing ingots.

The single mechanically-capped steel, B, exhibits a reversed trend with increasing porosity associated with teeming sequence.

The trends noted possibly relate to deoxidation practice which represents the only major difference among the steels. The semikilled steels received larger ladle-deoxidizer additions than the capped steels with ladle deoxidation continuing during teeming. Under this assumption, oxygen-content decrease should also be noted with teeming sequence. Complete oxygen data were

Table 4—Weld-Porosity Test Results; Aluminum-Capped Steels

Material location	Oxygen, %	Carbon, %	Sulphur, %	Porosity rating A1	A2	R1	R2	R3	% Defective ASME	R2
Steel D										
FTS		0.14	0.025	XX	X	XXX			50	0
FBS		0.20	0.029		X	X	X		67	33
MTS	0.011	0.21	0.029	X		XX	X		75	25
MBS	0.010	0.20	0.028	XX					0	0
LTS		0.20	0.028	XXXX					0	0
LBS		0.20	0.027	XXX	X				0	0
FTI		0.20	0.028	XXXXXX					0	0
FBI		0.21	0.028	XX	X				0	0
MTI	0.011	0.21	0.028	X	XX	X			25	0
MBI	0.011	0.19	0.024	XX	X				0	0
LTI		0.19	0.030	XXX	X				0	0
LBI		0.20	0.027	XX	X				0	0
Steel J										
FTS		0.12	0.032			X	X	X	100	67
FBS		0.10	0.020			XXX			100	0
MTS	0.013–0.011	0.12	0.037					XX	100	100
MBS		0.11	0.027			XX	X		100	33
LTS		0.11	0.032				XX	X	100	100
FTI		0.17	0.037			X	XX	X	100	75
FBI		0.14	0.037			XX			100	0
MTI	0.0055–0.0062	0.16	0.039		X	XX			67	0
MBI		0.14	0.037				XX	X	100	100
LTI		0.15	0.039				XX		100	100
Steel K										
MBS	0.014	0.16	0.037	XX	X				0	0
LTS		0.18	0.043		X	X	X		67	33
LBS		0.16	0.037	XX	X				0	0
MBI	0.013	0.16	0.037	XXX					0	0
LTI		0.18	0.039	XX		X			33	0
LBI		0.16	0.035	XX	X				0	0

Table 5—Weld-Porosity Test Results, Mechanically-Capped Steel

Material location	Oxygen, %	Carbon, %	Sulphur, %	Porosity rating A1	A2	R1	R2	R3	% Defective ASME	R2
Steel B										
FTS		0.13	0.020	X	X	XX			50	0
FBS		0.15	0.027	XXX		X			25	0
MTS	0.0075	0.14	0.019	X	X	X	X		50	25
MBS	0.0098	0.11	0.023	XX	X	XX	X		62	37
LTS		0.11	0.024			XXX	X		100	25
LBS		0.11	0.024			XX	XX		100	50
FTI		0.17	0.035	XXXXXX		X			14	0
FBI		0.16	0.035	XXX					0	0
MTI	0.011	0.17	0.036	XX	X				0	0
MBI	0.010	0.16	0.036	XXX	XX				0	0
LTI		0.17	0.051	XX	XX				0	0
LBI		0.15	0.039	XXX	X				0	0

Table 6—Effect of Edge Preparation on Weld Porosity

(Refer to Fig. 8 for Porosity Standards)

Material location	*Sheared edges with mill scale surface* X1	X2	X3	*Sheared edges with sand-blasted surface* X1	X2	X3	*Machined edges with mill scale surfaces* X1	X2	X3
Steel A, Aluminum-Silicon Semikilled									
FTS			XXX			XXX	XXX		
FBS		X	X	X	XX			XX	X
MTS					XX	X	XX	X	
MBS			XXX	X	XX			XXX	
LTS			XX	X	XX			X	XX
LBS			XXX	X	XX		X	XX	
FTI			XXX	X	XX			XXX	
FBI			XXX		XXX			X	XX
MTI			XXX		XXX			XX	X
MBI		X	XX		XXX		X	XX	
LTI			XXX		XX	X		XXX	
LBI			XXX		XX	X	X	XX	

Table 7—Percent of Test Welds Defective; Positional-Parameter Effects

As determined by ASME Boiler Code Weld-Porosity Standard (Fig. 3) and by special Graded Weld-Porosity Standard R2 (Fig. 4)

Aluminum-Silicon Semikilled Steels

Material→ / *Location ↓*	*Steel A* ASME	R2	*Steel E** ASME	*	R2	*Steel F** ASME	*	R2
First ingot	52	30	46	(100)	17		(0)	
Middle ingot	25	0	17	(50)	0	92	(100)	58
Last ingot	10	5	50	(25)	50	66	(100)	17
Top slabs	41	12	46	(67)	8	58	(67)	25
Bottom slabs	17	11	28	(50)	28	100	(67)	50
Sheet exterior	47	18	44	(50)	22	83	(67)	67
Sheet interior	11	6	33	(67)	12	75	(67)	8
All welds	29	12	38	(58)	17	79	(67)	37

Silicon Semikilled Steels

Material→ / *Location ↓*	*Steel C* ASME	R2	*Steel G** ASME	*	R2	*Steel H** ASME	*	R2
First ingot	100	70	41	(100)	41	23	(100)	17
Middle ingot	86	64	50	(50)	50	0	(100)	0
Last ingot	77	44	50	(100)	50		(0)	
Top slabs	92	62	41	(67)	41	17	(67)	17
Bottom slabs	83	57	50	(100)	50	6	(67)	0
Sheet exterior	100	89	87	(83)	87	23	(67)	17
Sheet interior	76	30	7	(83)	7	0	(67)	0
All welds	88	59	47	(83)	47	11	(67)	8

Aluminum-Capped Steels

Material→ / *Location ↓*	*Steel D* ASME	R2	*Steel J** ASME	*	R2	*Steel K** ASME	*	R2
First ingot	29	8	100	(100)	36		(0)	
Middle ingot	25	6	92	(100)	58	0	(50)	0
Last ingot	0	0	100	(50)	100	25	(100)	8
Top slabs	25	4	94	(100)	75	50	(33)	17
Bottom slabs	11	5	100	(67)	33	0	(67)	0
Sheet exterior	32	10	100	(83)	60	22	(50)	11
Sheet interior	4	0	93	(83)	55	11	(50)	0
All welds	18	5	97	(83)	58	17	(50)	5

Mechanically-Capped Steel

Material→ / *location ↓*	*Steel B* ASME	R2
First ingot	22	0
Middle ingot	28	16
Last ingot	50	19
Top slabs	36	8
Bottom slabs	31	15
Sheet exterior	65	23
Sheet interior	2	0
All welds	33	11

* Heats marked with asterisk incomplete with respect to all 12 positional variables of the test program. The degree of representation is shown parenthetically as percentage.

obtained for only one material, Steel A, as reported in Table 2. The average oxygen contents for the first, middle and last ingot of 0.019%, 0.014% and 0.019%, respectively, do not appear to bear out this hypothesis.

Ingot-Position Effects. Comparative review of Table 7 results reported for top and bottom ingot slabs indicates greater porosity in top than bottom cuts for Steel A, aluminum-silicon semikilled deoxidation practice. Steel E has unbalanced representation of slabs and is probably not valid for comparison. The trend is reversed for Steel F which is balanced but with the first ingot missing.

Steel C, silicon semikilled, has slightly greater pore sensitivity in top ingot slabs. Steel G is asymmetric with respect to slabs and is not compared. Steel H shows slightly greater porosity in top slabs although the last ingot is missing from this heat.

Of the aluminum-capped steels, D exhibits somewhat more porosity in top slabs. Steels J and K do not have balanced representation of this variable and so are not compared.

Steel B, sole mechanically-capped steel, exhibits essentially no difference in porosity sensitivity between top and bottom ingot material.

The differences in porosity susceptibility associated with this positional variable do not appear to be either pronounced or consistently present.

Sheet-Position Effects. All 10 steels exhibited, in varying degree, similar differential weld-porosity sensitivity with respect to sheet position, welds from sheet interior material being less porous than those from as-rolled sheet edges. Since most of the partially complete steels are equally represented for this positional parameter, any differential effect uniformly present in the steel and not affected by teaming sequence or ingot slab position should be observable. As previously noted, slab position effects were not marked in general whereas those of teeming sequence were more pronounced in the semikilled steels.

Of the aluminum-silicon semikilled steels, A shows quite clearly greater porosity in welds made from exterior sheet edges. This same trend, though less pronounced, is exhibited by Steel E. Steel F shows this same trend, also less marked than for Steel A but with more severe porosity.

The same effect is noted for Steel C, silicon semikilled, particularly the decreased interior sheet sensitivity to severe porosity as rated on the R2 standard. Steel G, from which only one slab was missing, shows both an extremely pronounced effect and more severe porosity. Steel H, lacking the last ingot, had porosity-free sheet-interior welds.

Table 8—Percent of Test Welds Defective, All Program Materials

As determined by ASME Boiler Code Weld-Porosity Standard (Fig. 3) and by special Graded Weld-Porosity Standard R2 (Fig. 4)

Deoxidation practice	*Steel*	*Porosity criterion*—*ASME*	*R2*	*Representation, % complete*
Aluminum-silicon semikilled	A	29	12	100
	E	38	17	58
	F	79	37	67
	C	88	50	100
Silicon semikilled	G	47	47	83
	H	11	8	67
	D	18	5	100
Aluminum capped	J	97	58	83
	K	17	5	50
Mechanically capped	B	33	11	100

The aluminum-capped steels all exhibited this same trend. Steel J, nearly complete with only one slab missing, showed more severe porosity than did Steels D and K, but porosity incidence for all was less for interior sheet positions.

Steel B, mechanically capped, clearly shows this trend although additional heats were not available for confirmation.

This sheet variation, observed in all steels of the investigation, appears to be the most valid effect associated with the positional parameters of the test program. Because of its common appearance, it could be of practical importance in pipe fabrication involving welding of as-rolled or skelp edges rather than edges sheared or slit from sheet. It would appear to be a segregation effect associated with ingot solidification and, possibly, rim or skin formation in the capped steels. Since sheet-interior edge materials were no closer than 6 in. to an as-rolled sheet edge, gradient effects related to ingot rim or skin probably would not appear in the test results.

Chemical segregation associated with sheet position was examined in detail for two of the complete materials: Steel A, representing semikilled deoxidation practice, which showed moderate differential porosity and for which complete oxygen analyses were available, and Steel B, a capped steel exhibiting more pronounced differential sensitivity. The average values are given in Table 10. It is seen that segregation is not pronounced in Steel A with oxygen variation the only notable difference, being lower for sheet interior material. Referring to Table 2 test results for this material, it is observed that welds for the LTI position with high oxygen content of 0.026% were uniformly sound whereas FBS position welds of the same oxygen content were uniformly porous. Similar erratic variation in terms of oxygen content can be seen in other welds of this steel.

Segregation is more pronounced in Steel B with carbon and sulphur significantly higher in the interior sheet material which exhibited the greatly decreased susceptibility to weld porosity. This behavior is contrary to commonly accepted experience which is generalized in the AWS Welding Handbook to the effect that sulphur can cause porosity through reaction with hydrogen from the arc atmosphere, becoming serious in excess of 0.05%, and that carbon in the base metal can cause porosity through reaction with oxygen from the atmosphere, shielding gases, flux oxides, or oxides from scale and inclusions.

In the present instance, it is not thought that the chemical effects here observed are responsible for the differential porosity sensitivity encountered, although it does appear related definitely to segregation.

Deoxidation-Practice Effects

Effects of deoxidation practice on porosity sensitivity are indicated in Table 8 in terms of percent defective welds for the two porosity criteria for each steel of the four deoxidation practices. Initial evaluation based only on the complete steels ranks the practices as follows: *best*, aluminum capped (Steel D); *second*, aluminum-silicon semikilled steel (Steel A); *third*, mechanically capped (Steel B); *worst*, silicon semikilled (Steel C). The ranking applies for both porosity standards, indicating porosity of similar severity in the four steels.

Test results for the partially-complete steels fail to validate this initial ranking, showing large variation among both steels and deoxidation practices. Comparing steels of the same deoxidation, Steel K is seen to agree closely with Steel D, the best complete steel, whereas Steel J, nearly complete, exhibits greatest pore sensitivity of all the steels.

While Steel E corresponds well with Steel A, second-best complete steel, comparison is questionable due to inadequate representation. However, Steel F, which lacked the first ingot, exhibits porosity sensitivity approaching that of Steel C, worst complete steel, and would probably be worse if the teeming sequence effect for semikilled steels were attributed to the first ingot.

The ranking for Steel B cannot be checked but the extreme variability noted for the other capped practice steels would indicate possibly similar non-uniformity in this practice.

Steel G was less pore sensitive than Steel C, worst complete steel, though still worse than Steel B, initial third ranking. However, the partial results show Steel H equal to Steel D, best complete steel. If the teeming sequence effect noted for semikilled steels were applied to the missing last ingot of this heat, Steel H would probably rank best of the program steels.

The test results indicate clearly that very real differences in porosity sensitivity exist between and among these

Table 9—Composition Variation, Test Program Materials

Element	*Mean, %*	*Standard Deviation, %*	*Range, %*
Carbon	0.167	0.031	0.17
Sulphur	0.0336	0.0071	0.032
Manganese	0.426	0.0357	0.18
Silicon	0.0484	0.0121	0.11
Aluminum	0.0198	0.0355	0.19
Phosphorus	0.0148	0.0053	0.024

Table 10—Segregation Effects, Exterior and Interior-Sheet Positions

Sheet edge position	*Analysis, %* O_2	C	S	Mn	Al	Si	P
			Steel A, Aluminum-Silicon Semikilled				
Exterior	0.019	0.148	0.030	0.465	0.008	0.028	0.008
Interior	0.016	0.143	0.032	0.475	0.006	0.030	0.009
			Steel B, Mechanically Capped				
Exterior		0.125	0.023	0.417	0.004	−0.01	0.010
Interior		0.163	0.039	0.437	0.004	−0.01	0.010

Table 11—Average Analyses, Test Program Steels

Ranked in Order of Increasing Weld-Porosity Susceptibility

Steel code and deoxidation	*Analysis, %*						
	O_2	*C*	*S*	*Mn*	*Si*	*Al*	*P*
H—Si S-K	0 0091	0 170	0 045	0 395	0 080	0 023	0 020
D—Al-Cap.	0 0107	0 196	0 028	0 448	0 010	0 061	0 015
K—Al-Cap.	0 0135	0 167	0 038	0 450	0 006	0 028	0 026
A—Al-Si S-K	0 0145	0 146	0 031	0 470	0 029	0 007	0 009
B—Mech.-Cap.	0 0096	0 144	0 031	0 426	—0 01	0 004	0 010
G—Si S-K	0 0195	0 204	0 037	0 391	0 091	0 002	0 021
F—Al-Si S-K	0 0102	0 169	0 031	0 450	0 023	0 007	0 018
C—Si S-K	0 0240	0 179	0 038	0 402	0 060	0 005	0 014
J—Al-Cap.	0 0089	0 132	0 034	0 387	0 020	0 055	0 012

10 steels. The fact that variations among heats of the same deoxidation practice are as great as those occurring among the four deoxidation practices indicates that deoxidation practice alone is not the major factor controlling weld-porosity susceptibility in these steels of otherwise nominally similar composition.

Composition Effects

The a priori differences among the test steels are those of deoxidation practice, minor chemical variations within the nominal composition range and segregation associated with positional variables of each steel. Weld-porosity results so far considered revealed positional sensitivity possibly related to segregation and further emphasizing composition effects. Consequently, since weld porosity basically involves chemical reactions, a final correlation of weld-pore susceptibility with composition was attempted.

Table 11 presents average analyses for each steel ranked in order of increasing porosity sensitivity as determined in the discussion of deoxidation effects. As discussed in the test procedure, data for oxygen are less comprehensive than for the other elements. They are included since oxygen should relate to deoxidation practice and possibly to porosity as a potential source for gas reactions.

Detailed consideration of the comparison of Table 11 fails to reveal any distinct correlations between weld-porosity susceptibility and steel composition. The first three least-sensitive steels all exhibit oxygen content lower than average; however, the worst steel has least oxygen of the entire series. Carbon variation among the ranked steels also fails to exhibit any trend or pattern; for example, the second-best steel, D, has next highest carbon content of all steels. The top ranking steel, H, exhibits highest sulphur content of the series. Variation among other elements is so slight that it is not believed to be significant.

Interrelationships among the several potentially effective variables, assumed to be primarily oxygen, carbon and sulphur, make a complex situation which is difficult to correlate. Possibly advanced statistical analysis might yield correlation factors for these variables. Lacking such analysis, it is believed that little or no correlation exists between weld-porosity susceptibility and oxygen, carbon or sulphur variability of magnitude present in the investigation. In consequence, the very real weld-porosity sensitivity variation observed for these steels must be attributed to other factors not isolated or identified in the investigation.

Summary and Conclusions

The 10 heats of nominally-similar low-carbon steels investigated exhibited marked variation in their susceptibility to formation of porosity during submerged-arc welding. Since test conditions emphasized porosity response, it should be noted that the severity of the porosity inherently present in the materials was less than that occasioned by inferior initial weld preparation permitting inclusion of mill scale in the weld zone.

The following conclusions concerning variability of weld-porosity sensitivity observed among the steels were established.

(1) Deoxidation practices represented in the test program (aluminum-silicon and silicon semikilled; aluminum and mechanically capped) were not a major controlling factor since the range of porosity susceptibility among heats of a given deoxidation practice was as great as that exhibited among the several practices.

(2) Variations in composition of those elements for which analysis was obtained (O_2, C, S, Mn, Si, Al, P) were not primary factors. Composition variations were not great for most elements and, where of possibly significant magnitude, were erratic and failed to correlate with observed weld-porosity variability.

Differential weld-porosity susceptibility with respect to positional variables observed within individual heats and among the 10 steels led to the following conclusions.

(1) Teeming sequence appeared associated with decreasing weld-porosity sensitivity for the semikilled steels. Explanation for this behavior in terms of greater deoxidation with increasing ladle holding time failed to accord with oxygen analyses available.

(2) Ingot slab-position effects were not marked and did not display any significant trend in occurrence.

(3) Differential response associated with sheet position was the most pronounced positional effect with all steels displaying greater pore-formation sensitivity in welds made from as-rolled sheet-edge material than from sheet-interior material. This general characteristic could be of industrial significance in pipe fabrication involving welding of as-rolled or skelp edges as contrasted with edges sheared or slit from sheet. Although not determined, gradient effects associated with as-rolled sheet edge material appear to be worth further investigation.

While differential weld-porosity sensitivity noted for positional variables appeared to be a segregation effect, the only slight correlation established with material composition was contrary to commonly accepted explanations of steel chemistry with respect to weld porosity.

Since causes for the variations in weld-porosity susceptibility observed were not isolated or ascertained by the investigation in terms of the information available for the steels, no recommendations can be made for modifications in melting or mill practice either to reduce the weld-porosity sensitivity of these steels or the variability exhibited among them.

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A QUANTITATIVE EVALUATION OF RESIDUAL-STRESS RELIEF IN PIPE WELDMENTS

A study of the effects of time, temperature and heating rate on the relief of residual stress in 4-in. diam SA 106 schedule 80 pipe

BY JACK E. COOK AND ROY B. McCAULEY

ABSTRACT. The distribution and relief of residual stress in 4-in. diam SA 106 Schedule 80 pipe was investigated in this study. A residual stress of 29,000 psi (close to yield point) was found near the weld reinforcement. The yield-point stresses had tension and compression values for the parallel (longitudinal) and the perpendicular (traverse) directions, respectively. Appreciable residual-stress relief was found at varying temperatures and soak times: 800° F, 90 min; 1000° F, 30 min; 1225° F, 15 min. Induction heating was used for stress relieving. The X-ray diffraction technique, without part sectioning, was used for residual-stress evaluation.

Introduction

This paper presents a study of the distribution and relief of residual stress in 4-in. diam SA 106 schedule 80 pipe butt welds. The effect of temperature, time at temperature (soak time) and rate of heating on stress relief was investigated. Induction heating, because of its increased speed and efficiency in heavy-wall sections, is being used in more stress-relief jobs every day. The possibilities of additional flexibility as to setup, faster rates of heating, shorter soak time and even maximum temperature have caused engineers to look to induction methodology. Therefore, this investigation was undertaken to examine the latitude in stress-relieving procedure which can permit savings by the application of induction heating. Quantitative measurements of residual stress were determined by X-ray diffraction. The conclusions drawn concern only the level of residual-stress values and no attempt has been made to relate these stress levels with the load-carrying ability of the joint or other mechanical or physical properties.

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It is important to note that the scope of this study is limited to the residual stress found in mild-steel pipe. A steel analysis of low-carbon content and of minimum alloy percentage normally presents an easily welded pipe with a heat-affected zone free of appreciable hardness and reduced ductility. Pipe-wall thickness of (0.337 in.) is also relatively thin and ordinarily would not require stress relief. However, in this study the specimen represents a size of reasonable shape and weight to facilitate X-ray diffraction analysis with the available equipment. The specimen, therefore, was chosen as a starting point for the fundamental work of establishing, quantitatively, the distribution and relief of residual stress in pipe weldments.

The X-ray diffraction method for residual-stress evaluation was chosen for its nondestructive nature and for its characteristic ability to determine severe stress gradients as found near a weld. The technique of this stress-evaluation method as applied to 4-in. diam pipe specimens is outlined in this paper. Longitudinal and transverse stress designations are used throughout this study. Longitudinal stresses refer to those acting parallel to the pipe weld. Transverse stresses refer to those acting perpendicular to the pipe weld.

The order of reporting presents: (1) the stress-evaluation procedure, (2) the stress distribution, (3) the relief of residual stress and (4) the conclusions.

Experimental Procedure

Test Specimen

The test specimen consists of two 4-in. long sections of 4-in. diam SA 106 Grade B (schedule 80) pipe beveled and butt welded together. The 3-pass butt weld was accomplished by manual-arc welding with E6010 electrodes. The specimen was tacked at four places equally spaced around the joint and then welded by rolling alternate quadrants into the flat position. The tacking and welding fixture consisted of a 3-in. piece of angle iron. "C" clamps were used to secure the specimens maintaining the correct root gap in the groove of the angle iron. The tacking and welding sequence was designed to balance the heat and weld-metal input, thereby minimizing distortion. The interpass temperature was held to room temperatures to avoid any effective preheat from previous weld passes.

Stress Relieving

The pipe specimens were stress relieved by induction heating with a 400 cycle alternating-current generator. The automatic unit provided a convenient means of programming the heating rate, the stress-relief temperature, the soak time and the cooling rate. All of these parameters were permanently recorded on a strip chart. The specimens were equipped with a thermocouple welded on the weld-reinforcement centerline. Two 30-in. sections of 4-in. pipe were used to position the 9-in. specimen. Three $^3/_8$- x 4-in. steel dowel pins were equally spaced and welded to the ID of the 30-in. pipe sections. The pins protruded from the ends approximately 2 in. and located on the ID of the specimen, thus positioning it. The specimen was then wrapped with asbestos which served to cushion and position the induction coil. The coil consisted of 28 turns of $^1/_4$-in. diam (glass-covered) annealed copper wire. The terminals of the coil were connected to the generator lead-out cables. Connecting the thermocouple to the programming control completed the setup. The specimens were stress relieved at various temperatures, heating rates, cooling rates and soak times as compiled in Table 1.

Specimen Surface Preparation

The X-ray diffraction method of stress evaluation requires that the speci-

Table 1

Specimen	Temperature, °F	Heating rate, °F/hr	Soak time, min	Cooling rate (down to 600° F), °F/hr
4	800	300	90	300
5	800	300	60	300
6	800	300	15	300
7	1225	300	60	300
8	1225	300	15	300
9	1225	300	3	300
10	500	300	30	300
11	800	300	30	300
12	1000	300	30	300
13	1225	300	30	300
14	1320	300	30	300
15	1225	600	30	600
16	1225	1000	30	600
17	1225	1600	30	600

men surface be smooth and free of contaminating oxide, scale or rust. The pipe specimens in this study were found to be pitted and rusted. Therefore, the following surface preparation was necessary:[1]

1. The spot to be irradiated was lightly filed to remove rust and pits. Coarse and light abrasive paper was then used to smooth the spot.

2. The cold working resulting from filing and sanding was removed by etching with 30% nitric acid (approximately 7 or 8 min of etching was required). A good indication of sufficient etch was obtained when the metal surface lost its luster.

3. Etch pits (if any) caused by Step 2 were smoothed with very fine abrasive paper.

4. The final surface was prepared for etching with a 10% nital solution (nitric acid in alcohol). Approximately 4 min of etching time was required.

Stress Evaluation

The residual-stress values were determined by X-ray diffraction. In this method, a fine beam of monochromatic (single wave length) X-rays impinges upon and is diffracted by the metallic structure. Bragg's Law of Diffraction ($\lambda = 2d \sin \theta$) sets up the geometrical requirements for diffraction in terms of the perpendicular distance (d) between a given set of parallel atomic planes, the wave length (λ) of the incident monochromatic radiation, and the angle of incidence (θ) between the incident radiation and the atomic planes. This law thus provides for the measurement of the d dimension. The d spacing of crystallographic atomic planes in a stress-free body is constant for a given temperature and is determined by the interatomic forces. When the metallic structure is distorted or elastically strained, as in the case of residual stress, the d value changes as the interatomic forces and thus the spacing between atoms adjusts to accommodate the acting stress. In welding, the residual stress is brought about by the localized plastic deformation resulting from the tremendous thermal forces rising from localized heating and cooling. Thus, a natural lattice strain gage is available in the structure of a metallic body since the d dimension changes with elastic distortion. Measurement of this change in d along with a stress equation developed from the theory of elasticity is the basis of the determination of residual stress.

The back-reflection technique is used for X-ray strain measurement since at large θ values small changes in d are magnified and accurately determined. The collimated beam of X-rays is passed through and at right angles to the photographic film. The beam strikes the specimen and is diffracted by atomic planes oriented such that the conditions set by Bragg's equation are satisfied. The diffracted radiation in the form of a cone with the incident radiation as its axis strikes the flat film forming an arc or circles. Measurement of the radius of arc along with the film-to-specimen distance yields the data for the calculation of the angle θ. In this work two exposures are required for the stress equation: one with the incident X-ray beam nearly perpendicular to the specimen surface (it gives strain perpendicular to surface) and one with the X-ray beam at 45 deg to the specimen surface normal (this gives strain in an oblique 45-deg direction).

In this study, a back-reflection camera was designed and built which would accommodate the pipe specimen. The OD of the camera was held at 4 in. to facilitate the 45-deg exposure. This was necessary to avoid interference of the camera OD and the specimen while maintaining a film to object distance of about 5 cm (2 in.). This distance is ideal for keeping exposure time to a minimum.

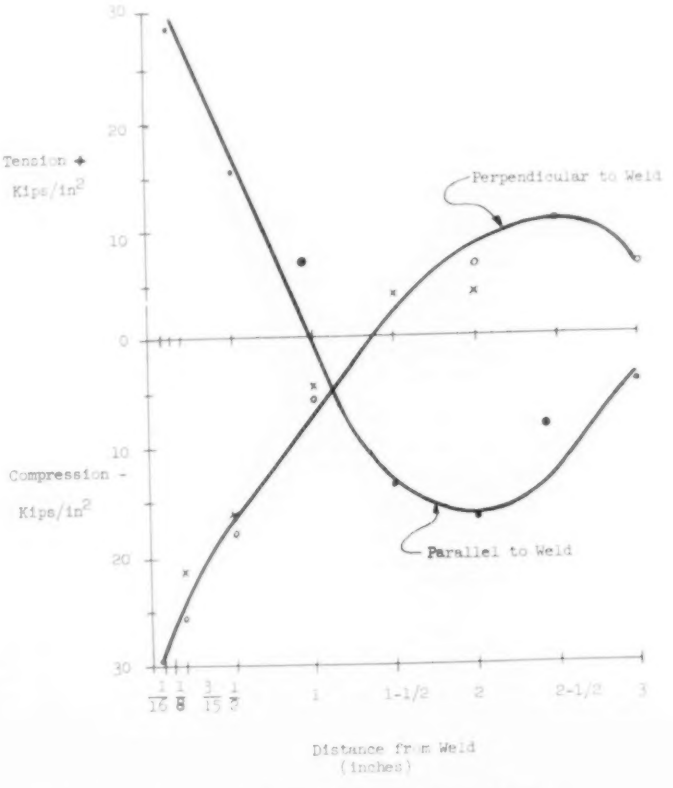

Fig. 1 Residual stress vs. distance from weld (as-welded)

The camera positioned the pinhole-collimating tube both at the center of the film and at right angles to the film.

The X-ray collimating system designed and used in this study consisted of two lead pinholes mounted in opposite ends of $\frac{1}{4}$-in. diam by 1-in. copper tube (ID = $\frac{3}{16}$ in.). The pinhole nearest the X-ray tube was 0.020 in. diam while the other pinhole was 0.028 in. diam. The pinhole tube was a slip fit into the camera bore. The 0.020-in. pinhole was positioned about $\frac{1}{4}$ in. behind the film (toward the X-ray tube) in accordance with the parafocusing technique.[2] The alignment of the pinhole to the X-ray target focal spot is very important if a minimum exposure time is desired. A quick method of obtaining alignment was used employing a fluorescent screen. The screen was taped onto a piece of leaded glass (4 x 6 x $\frac{1}{4}$ in.) and placed in the position of the specimen. Adjusting the camera and fixture assembly under operating conditions, until the brightest fluorescent spot is attained, results in the shortest exposure time. Proper shielding of the hands and other parts of the body cannot be overemphasized. The pinhole system defined approximately a $\frac{1}{16}$-in. diam spot on the fluorescent screen (film to specimen distance = 5 cm).

Chromium radiation was chosen because it produces a high-intensity reflection from the 211 planes at a θ angle of approximately 78 deg. The chromium tube was operated at 40 kvp and 10 milliamperes. The average exposure time of 1 hr provided sharp lines. The beta component of the incident radiation was removed by a vanadium filter.

The film-to-specimen distance was measured by a mechanical spacer. The spacer was designed such that after establishing the reproducible dimension it could be removed without disturbing that dimension. Stress evaluation is primarily concerned with the difference between the d values in two directions but not the absolute value of any particular d spacing. In this light, it was found that a mistake of as much as 0.003 in. in the film-to-specimen distance resulted only in a change of 300 psi in the pertaining stress calculation.

The specimen was fairly coarse-grained, as was shown by spotty diffraction lines obtained on a stationary exposure test. The spottiness is caused by the inadequate supply of properly orientated reflecting planes (grain orientation) in accordance with the Bragg Law for the cone diffraction. This situation is emphasized when a very small spot is irradiated on a coarse-grained specimen. The spottiness was easily smoothed into a continuous arc by oscillating the film ± 8 deg. Barrett[3] indicates that oscillation up to ± 30 deg can be made with negligible errors. The oscillation merely brings fresh film into the fixed reflected ray and thus ties the broken spotty ring into a continuous arc.

The film was developed, fixed, washed and dried in accordance with standard manufacturer's recommendations. The film-measuring device enabled reading to ± 0.005 cm. This reading accuracy corresponds to a stress-calculation accuracy of approximately ± 3000 psi.

The center of the film was found by measuring the diameter of the film hole which was held concentric to the pinhole tube by the common bore of the camera. The diffraction film line was measured by a method similar to that described by Greenough.[4] The line ($K\alpha_1$) was pricked on each side with a pin and then the center was pricked, based on the two boundary marks. A magnifying piece was used to facilitate this procedure, along with a rheostat control to modify the illumination of the film. The center of the film and line position were listed on a standard stress-evaluation form developed for this study. The semiapex angle (α) of the radiation cone was determined by dividing the film-line radius by the film-to-specimen distance. This ratio is, or course, the tangent of the angle α. This angle is related to θ (angle of reflection) by the equation $\alpha = 180° - 2\theta$. The angle θ thus determined was converted to radians and substituted into the following stress equation:

$$\sigma_\phi = \frac{\theta_\perp - \theta_\phi}{\tan \theta_0} \times \frac{E}{(1 + \gamma)\sin^2 \phi}$$

The above equation was derived from the theory of elasticity which assumes that the body is perfectly elastic, homogeneous and isotropic. The use of θ values rather than d dimensions saves calculating time. E is the modulus of elasticity taken as 30×10^6 psi. γ is Poisson's ratio, taken as 0.28. ϕ is the angle of the oblique exposure taken as 45 deg. $\theta_\perp$ is the perpendicular exposure value and θ_ϕ the oblique value. θ_0 is the unstressed θ value where θ_ϕ can also be used with little error.

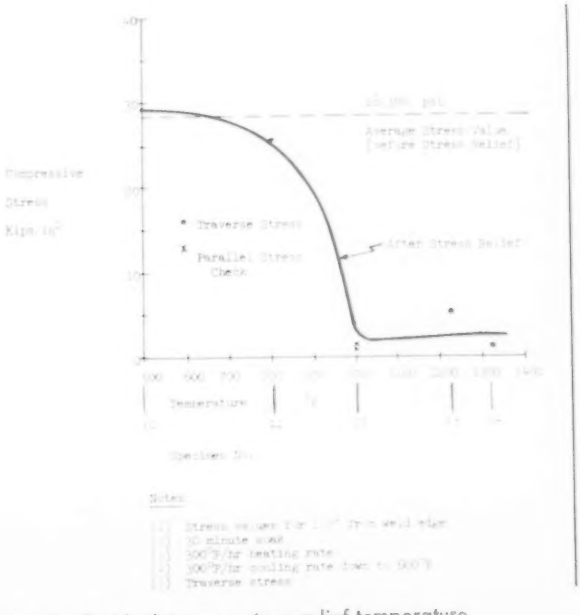

Fig. 2 Residual stress vs. stress-relief temperature

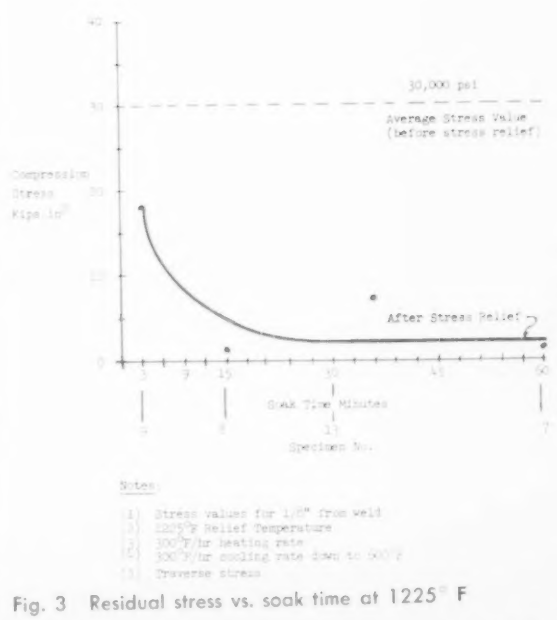

Fig. 3 Residual stress vs. soak time at 1225° F

Discussion of Results

Preliminary Test

Preliminary tests were conducted on as-received pipe, as-welded pipe and stress-relieved pipe. The as-received pipe was found to have 4800-psi compressive stress in the longitudinal direction (parallel to the pipe axis). The as-welded pipe was found to have 30,000-psi compressive stress at a point $\frac{1}{8}$ in. from the weld. This latter stress was perpendicular to the weld and will hereafter be designated as transverse stress. The as-welded pipe was then stress relieved according to standard practice; i. e., heated slowly in a furnace to 1250° F, soaked for 30 min and furnace cooled. The transverse stress was then found to be 1500 psi in compression. In other words, the stress-relieving procedure was apparently satisfactory.

The above results indicated that the stress-evaluation technique was yielding satisfactory results. The stress next to the weld was expected to be near the yield point (30,000 psi) since this area had experienced plastic flow. It was decided to study in detail the stress distribution at intervals away from the weld. The stress parallel to the weld was determined as well as the transverse stress.

The transverse and parallel stress values for the as-welded specimen were determined for intervals from the weld out to a distance of 3 in. from the weld. The results are plotted in Fig. 1. The parallel stress next to the weld was found to be tension, and its value approximated the yield point of the material (30,000 psi). This parallel stress decreases smoothly in tension value to 0 at about 1 in. from the weld and then changes to compression. The maximum compression value (17,500 psi) was found at the 2-in. position. This stress pattern can be explained by considering the action of the cooling (solidifying) weld metal on the base metal. The cooling weld tends to contract and is restrained by the colder (rigid) base metal. Therefore, the weld and adjacent base metal are in tension (near the yield point) and the rigid base metal is in compression. The tensile stress in the weld and adjacent base metal is balanced by the compression stress in the rigid base metal in accordance with the concept of equilibrium. The localized plastic upset in the base metal, resulting from thermal expanding forces, is the important factor causing residual stress. The transverse stress distribution (away from the weld) was found similar to the parallel stress pattern discussed above. The major difference as shown by Fig. 1 was that the stress next to the weld was compression. This transverse stress decreases in compression to 0 at about $1\frac{1}{2}$ in. from the weld and then changes to tension. The compression value for the transverse stress (stress perpendicular to the weld) was probably due to the nature of the annular pipe weld.

Table 2—Stress Relief and Stress Evaluation of Specimens Studied

Spec. no.	Stress direction and position (from weld edge)	Stress before relief (tension, psi, compression	Stress relief: Temp., °F	Stress relief: Soak, min	Stress relief: Heating, °F/hr	Stress after relief, psi
1	Longitudinal	−4,762	As-received pipe			
2	Parallel, in.					
	$\frac{1}{8}$	27,976	As-welded			
	$\frac{1}{4}$	15,576	As-welded			
	$\frac{1}{2}$	7,441	As-welded			
	1	−13,691	As-welded			
	$1\frac{1}{2}$	−16,964	As-welded			
	2	−8,829	As-welded			
	$2\frac{1}{2}$	−4,762	As-welded			
	3					
2	Transverse, in.					
	$\frac{1}{16}$	−29,960				
	$\frac{1}{8}$	−25,803	−21,032 check shot of same position on			
	$\frac{1}{4}$	−17,758	−16,964 opposite side of pipe			
	$\frac{1}{2}$	−5,556	−4,762			
	1	2,579	3,373			
	$1\frac{1}{2}$	6,647	3,373			
	2	10,714				
	$2\frac{1}{2}$	6,647				
	3					
3	Transverse, $\frac{1}{8}$ in.	−29,961	1250	30	Furnace test	−1,488
4	Transverse, $\frac{1}{8}$ in.	−21,826	800	90	300	−5,556
4	Parallel check, $\frac{1}{8}$ in.		800	90	300	3,373
5	Transverse, $\frac{1}{8}$ in.	−25,803	800	60	300	9,623
6	Transverse, $\frac{1}{8}$ in.	−42,163	800	15	300	−25,803
7	Transverse, $\frac{1}{8}$ in.	−38,086	1225	60	300	−1,488
8	Transverse, $\frac{1}{8}$ in.	−25,803	1225	15	300	−1,488
9	Transverse, $\frac{1}{8}$ in.	−26,380	1225	3	300	−17,758
10	Transverse, $\frac{1}{8}$ in.	−21,826	500	30	300	−29,961
11	Transverse, $\frac{1}{8}$ in.	−21,826	800	30	300	−25,803
12	Transverse, $\frac{1}{8}$ in.	−34,028	1000	30	300	−694
12	Parallel check, $\frac{1}{8}$ in.		1000	30	300	−1,488
13	Transverse, $\frac{1}{8}$ in.	−29,961	1225	30	300	−5,556
14	Transverse, $\frac{1}{8}$ in.	−34,028	1320	30	300	−1,488
15	Transverse, $\frac{1}{8}$ in.	−21,826	1225	30	600	−5,556
16	Transverse, $\frac{1}{8}$ in.	−21,032	1225	30	1000	3,373
16	Parallel check $\frac{1}{8}$ in.		1225	30	1000	2,579
16	Parallel check, $2\frac{1}{2}$ in.		1225	30	1000	−9,623
17	Transverse, $\frac{1}{8}$ in.	−34,028	1225	30	1600	−21,826

The transverse residual stress was chosen as the surface component to be measured for the subsequent evaluation of stress relief. This stress was chosen since the specimen could be accurately and easily positioned to accommodate the two exposure diffraction techniques for stress determination.

Residual-Stress Relief

The objective of this section is to present the effect of stress-relieving techniques on the maximum residual-stress value which was found at the $\frac{1}{8}$-in. position from the weld. The variables investigated are temperature, soak time and heating rate. The stress relief was accomplished by an induction generator. A master chart of all the specimens studied with information concerning their stress relief and stress evaluation is given in Table 2.

Temperature

The temperatures studied were 500, 800, 1000, 1225 and 1320° F. Stress determinations taken on each of the five specimens before stress relief indicated an average transverse compression stress of 28,300 psi at the $\frac{1}{8}$-in. position. Figure 2 shows a plot of the temperature versus residual stress after stress relief. The dotted line represents the 28,300-psi significant average stress value before stress relief.

The soak time for these specimens was held at the 30-min value which produced stress relief at 1225° F during the preliminary furnace testing. The heating rate was held at 300° F per hour along with a cooling rate of the same value down to 600° F. The width of the heated band was held at approximately four times the weld reinforcement (4 in.).

Figure 2 indicates that 1000° F is the minimum temperature under the above conditions at which significant stress relief is accomplished. A check of the 1000° F specimen indicated that the parallel stress at the $\frac{1}{8}$-in. position was also relieved to a low value of 1500 psi in compression. A significant factor contributing to stress relief at 1000° F (as well as 1225° F) is the relationship between yield strength and temperature. The yield strength of steel decreases with increasing temperature. Starting at values near 35,000 psi, the yield

strength decreases slowly at first and then very rapidly when the temperature reaches approximately 1000° F. The residual elastic stresses can be no greater than the yield strength since such stresses would relieve themselves by plastically adjusting to the value of the reduced yield strength. This factor of reduced yield strength at 1000° F, along with a 30-min soak time, are effective in reducing residual stress to a low value. The fact that the yield strength is reduced to about 10,000 psi at 1000° F indicates that the soak time is also an important factor in attaining the resultant stress relief to the low value of 1500 psi.

Soak Time

The effect of soak time was studied for both 800 and 1225° F. The time values chosen for the 1225° F temperature were 3, 15, 30 and 60 min. The time values for 800° F were 15, 30, 60 and 90 min. Plots of time versus residual stress are shown in Figs. 3 and 4. Dotted lines on the above plots indicate the average residual stress in the specimens studied before stress relief. The heating rate, cooling rate and band width were held to the same values indicated under the above temperature tests.

The 1225° F temperature plot (Fig. 3) indicates that a soak time of 15 min minimum will effectively relieve the residual stresses. It should be noted that even a 3-min soak was effective in partially reducing the residual stress.

The 800° F temperature plot (Fig. 4) indicates that a soak time of 90 min is effective in relieving the residual stress to a low level. A check shot of the 90-min specimen indicated that the parallel stress at the $\frac{1}{8}$-in. position was also relieved to a low value of 3,400 psi in tension.

Heating Rate

The effect of the heating rate was studied for a temperature of 1225° F and a 30-min soak time. The approximate 4-in. heated band width was maintained. The cooling rate was increased from 300 to 600° F /hr in an effort to produce critical conditions both from the standpoint of heating rates and cooling rates. The heating rates chosen were 300, 600, 1000 and 1600° F /hr.

Figure 5 shows a plot of heating rate versus residual stress under the above conditions. This plot indicates that heating rates up to and including 1000° F /hr coupled with a temperature of 1225° F and a 30-min soak were effective in relieving the residual stresses next to the weld.

Check spots of the parallel stresses on the 1000° F /hr specimen were taken at the $\frac{1}{8}$-in. position and also the $2\frac{1}{8}$-in. position from the weld. The $\frac{1}{8}$-in. position showed the residual stress relieved to a low value of 2500 psi in tension. However, the $2\frac{1}{8}$-in. position showed a compressive stress of 9600 psi. It is interesting to note that the $2\frac{1}{8}$-in. position is approximately at the tapering off limit of the 4-in. heated band width. The temperature gradient at this point, brought about by the rapid heating rate, is probably the cause of the stress value found in this area.

Whether or not this 9600-psi stress value is critical at this distance from the weld is not the objective of this study. The important point is that the stress value is not in the heat-affected zone of the weld. This aspect would be of considerable importance if the specimen were a hardenable material and the heat-affected zone were thus subject to reduced ductility and increased hardness.

Conclusions

This investigation of residual stress and its relief in 4-in. SA 106 schedule 80 pipe weldments has resulted in the following conclusions:

1. The stress parallel to the weld in the as-welded specimen was found to be approximately 29,000 psi in tension ($\frac{1}{8}$ in. from weld). This stress dropped smoothly and changed to compression at about 1 in. from the weld. The compression stress reached a maximum of 15,000 psi at the 3-in. position (see Fig. 1).

2. The stress perpendicular to the weld (transverse stress) followed the same pattern as the above parallel stress except that it started at approximately 29,000 psi in compression and changed to tension about $1\frac{1}{4}$ in. from the weld (see Fig. 1).

3. A minimum temperature of 1000° F coupled with a 30-min soak, a 300° F /hr heating rate, a 300° F /hr cooling rate down to 600° F, and a heated band width of about 4 in. was found to relieve the residual stress effectively ($\frac{1}{8}$ in. from the weld) (see Fig. 2).

4. A soak time of 15 min coupled with a 1225° F temperature and the

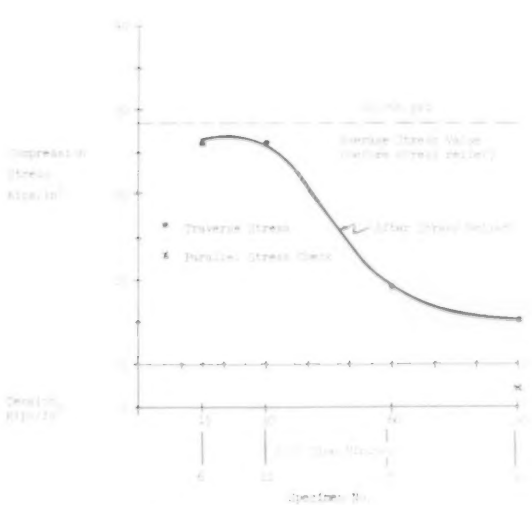

Fig. 4 Residual stress vs. soak time at 800° F

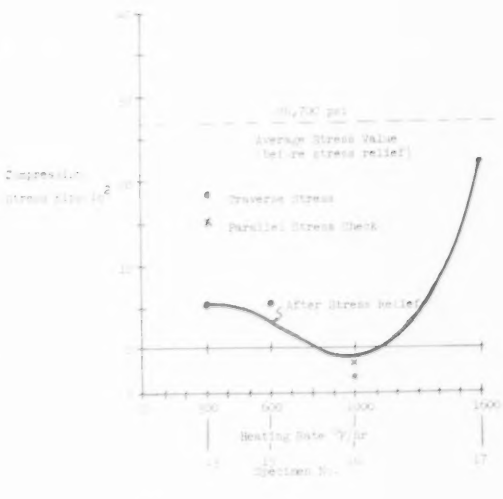

Fig. 5 Residual stress vs. heating rate

other factors listed in Item 3 were found to relieve the residual stress (see Fig. 3).

5. A soak time of 90 min coupled with a 800° F temperature and the other factors listed in Item 3 were found to relieve the residual stress (see Fig. 4).

6. A heating rate of 1000° F/hr coupled with a 1225° F temperature, a 30-min soak, a 600° F /hr cooling rate down to 600° F, and a heated band width of about 4 in. were found to relieve the residual stress (1/8 in. from the weld) (see Fig. 5).

Acknowledgment

The use of the X-ray unit, darkroom and other facilities of the Metallurgical Engineering Department, Ohio State University, were made available by Dr. Mars G. Fontana, chairman of the Department of Metallurgical Engineering. Dr. Erwin Eichen, also of the Metallurgical Engineering Department, was most helpful in frequent council concerning X-ray procedures. W. L. Green, instructor in the Department of Welding Engineering, Ohio State University, was instrumental in securing the pipe used in this evaluation. Professor Robert S. Green, executive director of the Engineering Experiment Station, Ohio State University, was very helpful in offering suggestions concerning the experimentation. Dr. C. Schwartz and D. Vaughn of Battelle Memorial Institute were very helpful in discussions concerning X-ray diffraction technique early in this study. G. Williams and J. Scott of Hobart Brothers Co., Troy, Ohio, played a key role in the success of this project by stress relieving all of the pipe specimens on their new 400-cycle program controlled high-frequency induction heating unit. To all of these people, we offer our deepest thanks.

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(Continued on page 192-s)

DYNAMIC MEASUREMENT OF STRESS ASSOCIATED WITH WELD CRACKING

Techniques and specimen geometries have been developed which permit dynamic measurement of stresses during and after welding through interpretive use of conventional strain gages

BY S. S. WHITE, W. G. MOFFATT AND C. M. ADAMS, JR.

ABSTRACT. The problem of stress buildup and cracking has been studied by experimental and theoretical techniques which permit use of conventional resistance strain gages on samples being welded to measure and analyze welding stresses during and after welding. In the absence of preheat, the maximum level of stress which precedes cracking appears to be substantially independent of the detailed nature of applied restraint forces and welding conditions. The analysis used permits estimation of transverse distributed load across a test weld at any instant, regardless of plastic deflections which may have occurred in the weld region.

Introduction

In almost all applications of fusion welding, local temperature variations are present to create strains which result in stresses. These local strains initiate at the onset of welding and continue to exist and vary throughout welding and subsequent cooling, and, in general, bear no simple relationship to local stresses, since thermal and elastic strains are superimposed on those reflecting phase changes and creep or plastic flow.[1]

Although stresses exist in a welded specimen both during and after welding, only those remaining after the specimen has completely cooled have received much experimental attention; such stresses are called residual or static stresses, and much work has been done to measure the distribution of residual stresses in welded joints. In an interpretive literature survey, Palme, Udin and Wulff[2] point out that, in almost every investigation, residual stresses of yield-point magnitude have been detected in weldments of significant size. Relief of such stresses has occupied many reports.[3,4] However, despite the volume of material, there is as yet no quantitative theory which can reliably predict the magnitude of residual stresses in weldments. This is due primarily to the fact that such theories are usually based on elastic-plastic conditions which are either oversimplified or require physical data not yet available. This is even true of the qualitative theory of Bierett and Rosenthal,[5,6] one of few which have enjoyed any success. In an attempt to improve upon this approach, Leykin[7] has attempted to account for the rapid decrease in elastic limit with rising temperature. This is a particularly difficult step to take since the temperature of a specimen varies from point to point and the variation of elastic limit or modulus with temperature is not known with high precision. Various investigators estimate the temperature at which mild steel appears to lose all elastic characteristics, independent of the time effect, to lie anywhere between 300 and 650° C.[3,8]

Recently, the maximum level of residual stress, which can be achieved without weld cracking, has been determined by a procedure which involves the ultimate destruction of the specimens.[9] While cracking and residual stresses are determined statically, dynamic records for transverse and longitudinal restraint are obtained. However, these records are determined on the restraining fixture and not the specimen, and interpretation is limited.

As for the problem of dynamic stress development, during and after welding, the literature reveals a few theoretical approaches, such as that of Boulton and Martin,[10] which entirely neglects plastic flow. Stresses and strains parallel to the welded edges of an edge-welded plate are predicted, at all times during welding, in terms of thermal dimensional changes induced by a moving heat source.

From an experimental standpoint, dynamic measurement of stresses in or near a weld during cooling requires a technique which is not sensitive to plastic flow or phase transformations in the region of the weld. Furthermore, the interpretation of results should not rely upon analytical formulation of a high-temperature post-yield stress-strain law. Even if wholly satisfactory high-temperature strain gages were available, conversion of strain to stress would be highly problematical. The only hope for obtaining transient stress information is to measure and interpret the actual over-all loads exerted by the cooling and contracting weld upon its surroundings, and hence upon itself. One of the major objectives to be served by such study is detailed understanding of weld cracking. And, of course, no amount of post-hoc residual stress measurement will shed much light on the magnitude of stress associated with cracking.

Experimental Procedure

All the experiments performed were carried out on (0.30% C, 1.63% Mn, 0.44% Mo, 0.29% Si, 0.016% P, 0.013% S) heat-treated ½-in. armor plate. This same material was used in prior studies.[11–14] A specimen type was desired which could be machined from a single piece of plate, in which any welding restraint was self-contained, in which a groove of length and configuration suitable for welding could be machined, and on which strain gages could be mounted in positions where the welding heat would not seriously influence strain readings. All of these requirements were met by a slotted plate of design similar to that first introduced by the Naval Research Laboratory.[15]

Three different sets of dimensions, three plates per set, were used with the NRL slotted plate. In addition, one plate was machined to one set of dimensions from low-carbon mild steel for preliminary study. These dimensions are shown in Figs. 1 through 3. This allowed a total of ten tests to

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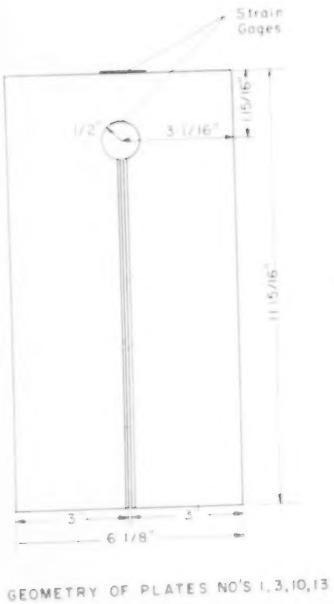

GEOMETRY OF PLATES NO'S 1, 3, 10, 13

Fig. 1 Dimensions of Type I slotted plate (NRL-type) test specimens indicating strain gage locations

All plates 1/2 in. thick. Welding groove: 60-deg included angle, 1/16-in. land, 1/16-in. root opening

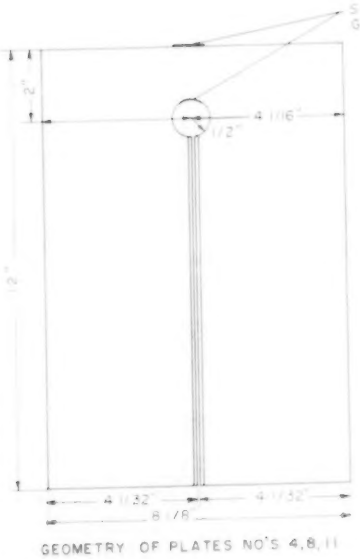

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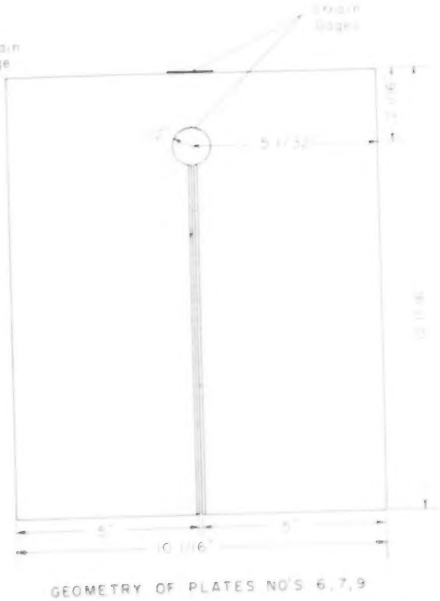
Fig. 2 Dimensions of Type II slotted plate (NRL-type) test specimens indicating strain gage locations

All plates 1/2 in. thick. Welding groove: 60-deg included angle, 1/16-in. land, 1/16-in. root opening



GEOMETRY OF PLATES NO'S 6, 7, 9

Fig. 3 Dimensions of Type III slotted plate (NRL-type) test specimens indicating strain gage locations

All plates 1/2 in. thick. Welding groove: 60-deg included angle, 1/16-in. land, 1/16-in. root opening

be performed. As shown in Figs. 1 through 3, two strain gages were mounted on each specimen, the line connecting strain gage centers being an extension of the weld centerline. Thus, direct measurement of separating force and bending moment exerted by restraint upon the weld was possible.

Calibration

After strain gages were mounted in the usual way,[16,17] all plates were calibrated by preloading in a tensile testing machine before welding. A typical calibration loading condition and result is shown in Fig. 4. In all cases a compressive load was applied 1 in. from the open end of the weld groove, in such a way as to close the groove partially, place the inside strain gage in compression and the outside one in tension. Only Type SR4-A7 1/4-in. gage-length strain gages were used. Strain readings were directly proportional to applied loads, exhibiting simple elastic behavior, without buckling.

Welding

After calibration, the plates were mounted on a motorized, movable carriage and welded with a fixed-position inert-gas-shielded metal-arc unit, so that travel speed, arc voltage, arc amperage and arc length could be maintained constant during each run. Argon with 1% oxygen was used for gas-shielding. Welding conditions are summarized in Table 1.

In all but one case, the weld was initiated at the plate-edge of the groove, and travel was in a direction toward the strain gages. In some cases, the weld was carried all the way to the 1-in. diam hole at the other end of the groove; and, in the remaining plates, the weld was terminated several inches short of that point. Welds of varying lengths were produced in an effort to vary the severity of restraint, the purpose being to avoid cracking in some welds and, thereby, establish limiting cracking conditions. However, as it developed,

Table 1—Welding Conditions

Plate	*Type*	*Filler*	*Volts*	*Amperes*	*Weld length, in.*	*Rate of travel, ipm*	*Energy input, K, joules/in.*
1	I	I	34	340	3 4	12 6	56 4
3	I	I	34	340	5 9	12 6	56 4
10	I	I	34	340	8 9	31 8	22 0
13 (mild steel plate)	I	I	34	340	9 5	31 8	22 0
8	II	I	34	340	9 5	12 6	56 4
6	III	I	34	340	8 5	12 6	56 4
4	II	II	34	340	8 9	16 8	41 4
11	II	II	34	340	9 4	16 8	41 4
9	III	II	34	340	5 8	16 8	41 4
7	III	II	34	340	8 4	33 6	20 7

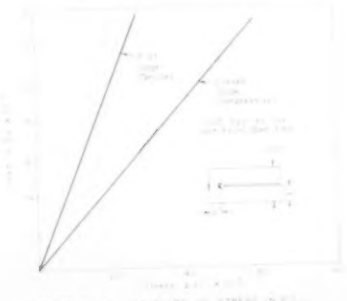


Fig. 4 Calibration curve for Type I plates

all welds were sufficiently restrained to crack.

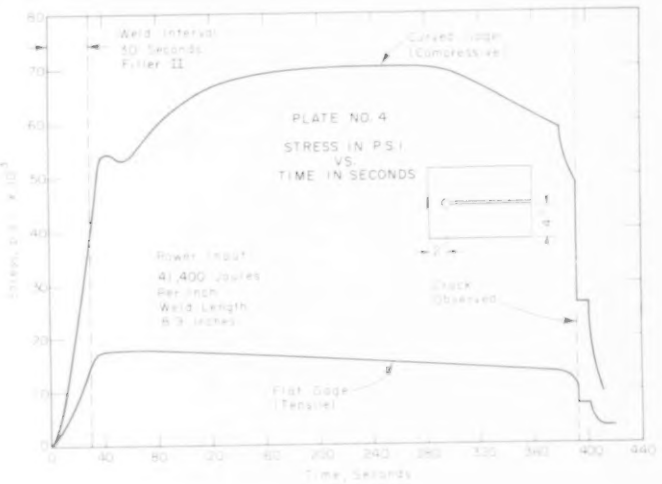
To determine the effect of filler composition on cracking, two types of filler

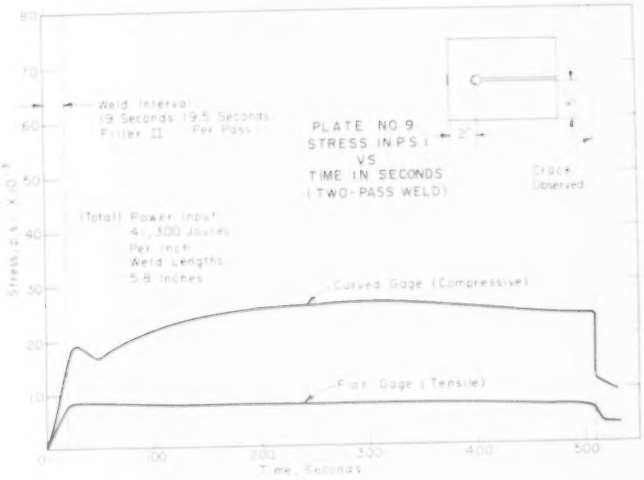
Table 2—Filler Wire Compositions, %

	Type I	*Type II*
C	0.35	0.08
Mn	1.00	1.22
Si	0.45	0.50
P	0.020	0.014
S	0.020	0.025
V	0.18	0.14
Cr	1.10	0.10
Ni		1.30
Mo		0.48

wire were used for most of the investigation, low-alloy medium- and low-carbon steel (compositions are presented in Table 2). Also, to determine the effects of extreme variations in hardenability and yield strength, single tests were conducted using (*a*) mild-steel filler on hardenable plate and (*b*) medium-carbon low-alloy filler on mild-steel plate. Figure 5 shows typical

Figure 5 (Top) Filler I, armor-plate base material. Straight crack shown in insert is typical of rapid crack propagation. (*Center*) Mild-steel filler, armor-plate base material. Crack shown in insert is typical of slow crack propagation through heat-affected zone. (*Bottom*) Filler 1, mild-steel base-material





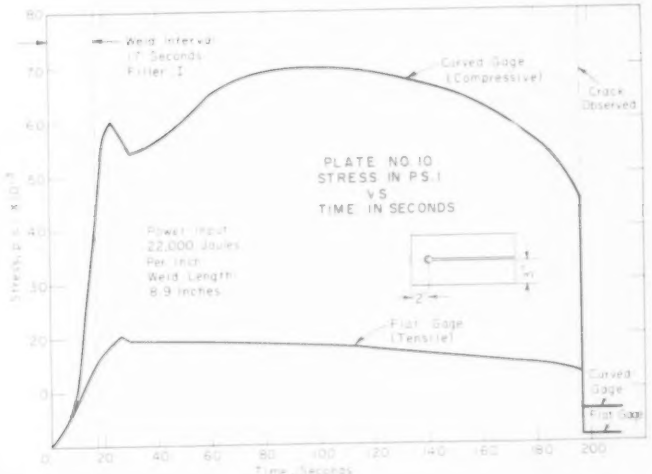


Fig. 6 Typical stress histories during and after welding of slotted plates. Stress at each gage location plotted versus time from the initiation of welding

fusion zone and crack configurations.

Single "V" joint preparation with a 60-deg included angle, $\frac{1}{16}$-in. root opening and $\frac{1}{4}$-in. land was used in all tests. From measured carbon contents and the known compositions of the filler wires and plate, it was determined that the fusion zone consisted of approximately 70% filler wire and 30% fused base metal. It was also found that cracks usually propagated partly through the heat-affected zone and partly through the fusion zone.

Stress Measurement

A twin-channel Sanborn recorder was used to plot stress at the two locations versus time, starting at the initiation of welding. Temperature compensation was achieved by placing unmounted dummy gages in contact with the plate near the active gages. The temperature never exceeded 130° F at strain gage locations. In most tests, strain recording was continued until cracking had initiated. Typical stress versus time charts are shown in Fig. 6. (Strain versus time is shown in Fig. 7 for a mild-steel plate in which yielding occurred at the strain gage location.)

In general, the stress did not drop completely to zero upon cracking; the crack never propagated the entire length of the weld, and stress was not fully relieved by cracking. In all but one case (Plate 8), maximum transverse loads and cracking developed after at least one minute had elapsed following completion of the weld, at a time when the weld region had cooled to below 200° F.

Stresses developed during welding were minor compared to those which followed welding. Immediately after completion of the weld, a relaxation in stress was frequently observed on the curved (compressive) gage before the maximum load was realized. This had tentatively been interpreted as an indication of discontinuous yielding of part of the weld.

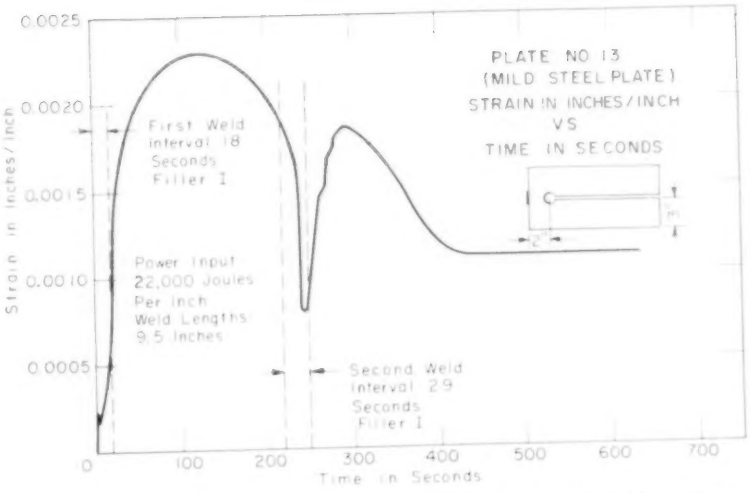


Fig. 7 Strain at curved gage location versus time in welding mild-steel plate specimen (Type I, Fig. 1). Two-pass weld in which yielding occurred at gage location

Interpretation of Results

In calibration, as well as in welding, that section of metal between the strain gages was subjected to compression in a direction perpendicular to the weld centerline, combined with bending. By subtracting the known net compressive force across this section, the strain gage readings which would have been obtained under conditions of pure bending could be determined, and the ratio of these two pure bending stresses, a constant, could be calculated.

Using this stress ratio and considering the material between the strain gages as behaving like a misshapen curved beam, the neutral axis of the beam could be located. This axis was always found to lie between $\frac{1}{3}$ and $\frac{1}{2}$ the way from the inside to the outside strain gage. With the calculated neutral axis location and the original calibration data, bending moments and separating forces during and after welding could be calculated as outlined in Appendix I.

Values for the combined separating force and bending moment sustained by the welds are listed in Table 3. No particular trend or consistency is evident in these values. Therefore, further interpretation in accordance with the concepts of beams on elastic foundations was required to estimate the magnitude and distribution of transverse stress across the weld which arose as a consequence of the applied separating force and bending moment.

Beams on Elastic Foundations

The two halves of the slotted plate may be considered as beams which are joined parallel by the weld. In other words, that portion of the plate adjacent and parallel to the weld is considered as a beam whose length is equal to that of the weld. These "beams" are acted

Table 3—Maximum Load Conditions of Welds Prior to Cracking

Plate	Type*	Filler	K, Joules/in.	Weld interval, sec	Time after end of welding, seconds	Weld length, in.	S_1 (curved) gage, compression	S_2 (flat) gage, tension	Total separating force, V, lb	Bending moment at inside end of weld, M, in.-lb	Load intensity at inside end of weld, $-q_0$ lb/in.
1	I	I	56.4	16	110	3.4	33,000	11,250	2,220	−10,570	10,117
3	I	I	56.4	25	700	5.9	67,000	21,000	5,190	−13,124	12,570
10	I	I	22.0	17	80	8.9	65,000	16,000	7,180	−2,990	9,420
8	II	I	56.4	40	25	9.5	97,200	28,000	8,475	+7,820	1,237
6	III	I	56.4	40	100	8.5	80,000	16,500	16,070	−21,070	14,470
4	II	II	41.4	30	250	8.9	70,000	15,000	8,800	−5,210	8,470
11	II	II	41.4	34	900†	9.4		45,000			6,800†
9	III	II	41.4	19	300	5.8	26,500	8,500	3,869	−12,820	6,547
7	III	II	20.7	14	400	8.4	37,700	7,000	7,950	−11,910	7,310

* Type I, Fig. 1; Type II, Fig. 2; Type III, Fig. 3.
† Estimated by comparison with Plate No. 8.

upon at one end by a separating force and the bending moment. The weld acts so as to prevent the two beams from becoming separated by exerting an equal and opposite force and bending moment on the beams. Each beam then acts as if it were mounted on an elastic foundation, and the combined force and moment were being exerted at one end in an effort to lift it from its foundation. The mathematics of this situation are outlined in Appendix II.

In order to use the concepts of beams on elastic foundations, an important number, called the foundation modulus, must be known. If the objective of the calculation in this case is the prediction of how the centerline of the beam is displaced from the centerline of the weld under the applied force system, the foundation would have to include that half of the beam between its centerline and the weld, as well as half the weld. Since the weld region itself is of complicated geometry and at high temperature during loading, the total modulus is unknown, and absolute displacements cannot be calculated. However, if it is only desired to determine transverse stress, irrespective of transverse displacement, only the modulus of the truly elastic part of the foundation need be known. The total displacement of the beams from each other is influenced by the unknown amount of plastic deformation which occurs in the immediate weld region during cooling; the final transverse stress distribution through the weld is largely independent of total displacement, and is governed only by the elastic properties of the foundation and the end loading conditions. Consideration of the welded members as beams on elastic foundations represents the only technique for stress analysis which is applicable without detailed knowledge of the elastic-plastic behavior of the weld region itself.

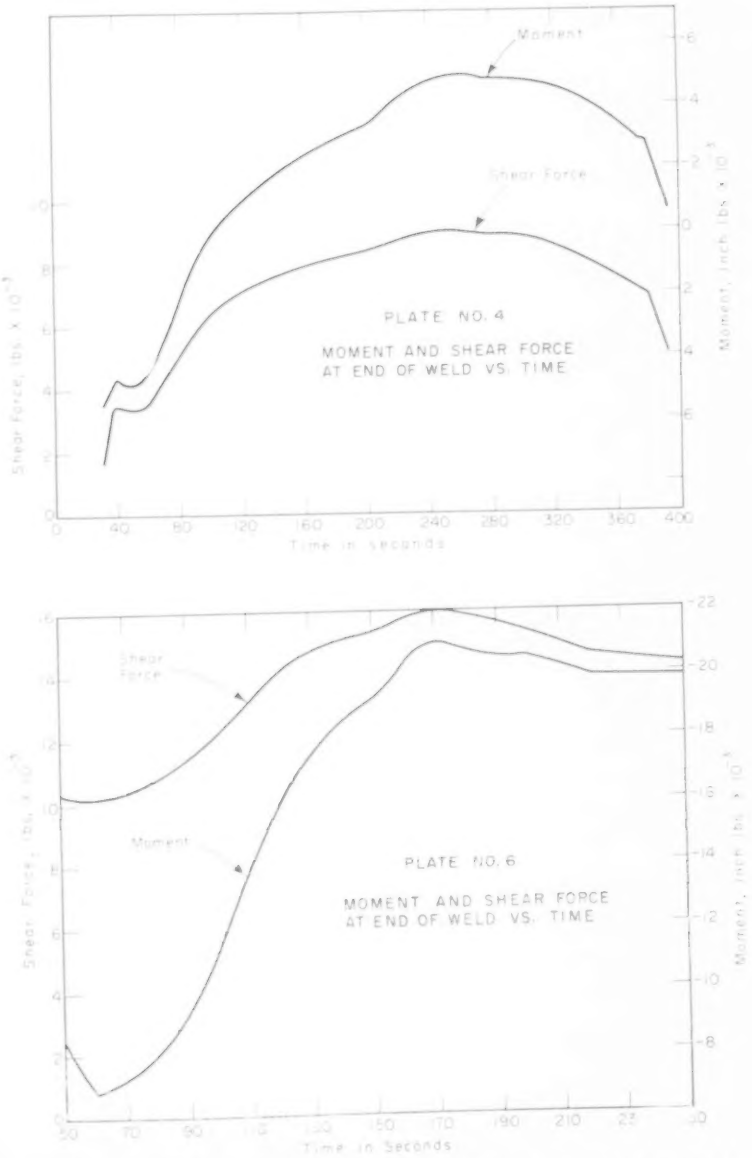


Fig. 8 Moment and shear force histories at inside end of weld after welding Plates 4 and 6. Maximum values reflect maximum transverse weld-load intensities before cracking

If experimentally, displacements had been measured instead of end loading conditions, application of the theory would have required complete knowledge of plastic behavior. If end-loading conditions and displacements had *both* been measured, unique and valuable information would have been obtained on the plastic behavior of the cooling weld region; this should certainly be a major objective of future investigations.

Through the use of relationships set forth in Appendix I, the stress-versus-time data of Fig. 6 can be directly transformed into terms of equivalent end-loading conditions. At all times during a run, a stress value is recorded by each gage, and, with the help of the calibration, these values can be converted into the total separating force acting upon the weld and the bending moment acting on each half of the plate (i.e., each "beam") at the end of the weld. As the strain gage values vary continuously with time, so must the separating force and bending moment vary with time, and this variation is exemplified for Plate Nos. 4 and 6 in Fig. 8. Measured stresses and calculated separating forces and (absolute) bending moments pass through maxima at about the same time. All subsequent computations of cracking stress were based on these maxima, in much the same way that ultimate tensile strength is computed on the basis of maximum load sustained during a tensile test. Actually, there was considerable evidence of plastic yielding after the maximum load had been realized; the decrease in load registered by the strain gages prior to cracking can be explained in no other way. In general, the separating force and bending moment maxima coincided in time closely enough that there was little difficulty in selecting maximum load conditions. In Fig. 8, as well as in the following paragraphs, from the standpoint of beam theory, the separating force is sometimes referred to as a shear force since it acts perpendicular to the neutral axis of the beam; in other words, the separating force is trying to shear each

leg of the plate along a plane perpendicular to the weld axis.

The maximum shear force and simultaneous bending moment withstood by each weld are listed in Table 3. It may be seen that the maximum shear or separating force varied from one to eight tons, and the bending moment prevailing at the inside end of the weld from −21,000 to +8000 in.-lb, and that many combinations of separating force and bending moment can induce cracking. Under these simple end-loading conditions, the maximum transverse tensile stress in the weld was obtained at the inside end of the weld where the load was applied. This stress, determined for each plate with the aid of the corresponding maximum separating force and bending moment already determined, is listed in Table 3. That is, considering the beams to be infinitely long (a valid assumption since the length of the weld was always greater than the distance from the weld to the edge of the plate parallel to the weld as shown in Appendix II) the following is true:

$$-q = 2J(V - JM)$$

where:

$-q$ = tensile load intensity, pounds per lineal inch of weld, at the inner end of the weld.
V = shear force, pounds, at the inner end of weld.
M = bending moment, inch-pounds, at the inner end of the weld.
J = 1.565 divided by h, in.$^{-1}$
h = distance from the weld centerline to the outer long edge of the plate, inches.

A separating force which acted to open the weld was taken as positive, and a bending moment which acted to curve the beam toward the weld and oppose cracking was taken as positive, in accordance with usual sign conventions. A large negative bending moment and/or a large positive shear force acting at the inner end of the weld caused high tensile stresses there. A typical load intensity history at the inside end of a weld (Plate No. 4) is shown in Fig. 9. Also, the load intensity distribution at peak loading during cooling for Plates 4 and 6 is given in Fig. 10.

The maximum load intensities present a much more consistent picture than any of the other measured or calculated quantities. Regardless of the way in which the load was applied, the maximum tensile loading the inner end of the weld endured, during cooling, fell within fairly narrow limits reflecting the "warm" strength and ductility of the weld. Most of the medium-carbon hardenable filler welds failed between 10,000 and 14,500 lb per inch of weld. One of the medium-carbon filler welds failed at 9000 lb per inch (Plate No. 10), but was welded with half the energy input of the others. The only medium-carbon filler weld which was carried the entire length of the groove experienced its maximum load very soon after the end of welding, and exhibited a much lower strength, presumably because yielding occurred at a higher temperature. Most of the medium-carbon filler welds survived at least a minute before cracking was detected, and Plate No. 3 did not crack until more than ten minutes after welding, after strain recording had ceased.

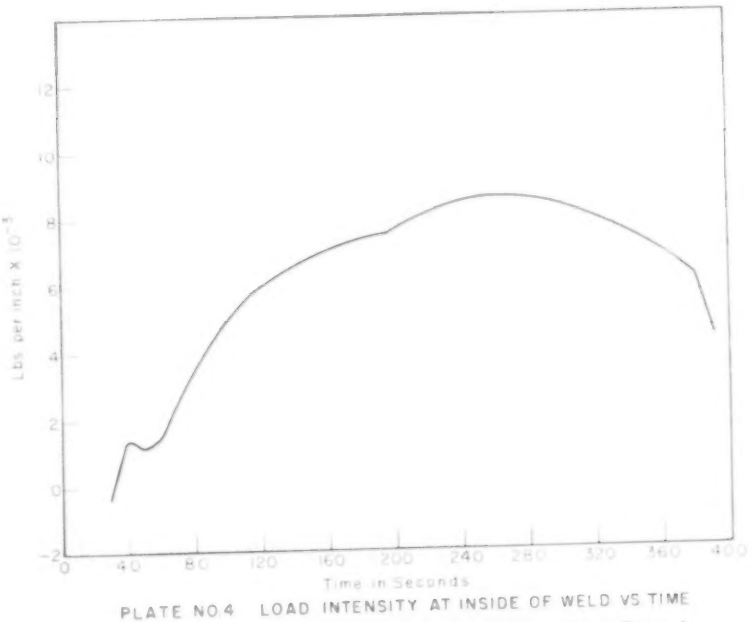


Fig. 9 Load intensity history at inside end of weld after welding Plate 4

The low-carbon, low-alloy filler welds failed between 6500 and 8500 lb per lineal inch of weld, and more time was required for cracking to initiate. More plastic flow appeared to precede cracking of the low-carbon filler than of the high-carbon filler. The only two-pass weld was performed on Plate No. 9, in which the two passes were deposited in rapid succession by reversing the direction of welding without interrupting the arc. There was little effect on maximum load prior to cracking. Plate No. 7 was welded with low energy input and an extremely porous weld was produced; neither factor greatly influenced maximum load conditions which preceded cracking.

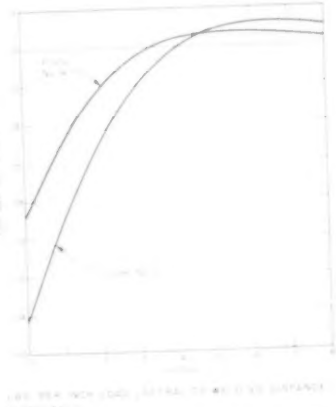


Fig. 10 Transverse load intensity distribution at peak loading during cooling of Plates 4 and 6

Load intensity expressed as pounds per lineal inch of weld. Negative values correspond to tension and positive to compression. Distance measured from inside (high tension) end of weld

Several measurements indicated the load carrying depth of the fusion zones, at the inside end, to be about $^{3}/_{16}$ in. for Plate Nos. 1, 3 and 10, and $^{1}/_{4}$ in. for Plates 4 and 9. The maximum tensile stress carried by the medium-carbon fusion zone was, therefore, probably between 35,000 and 45,000 psi, and for the low-carbon fusion zone from 20,000 to 25,000 psi.

Conclusions

1. Techniques and specimen geometries have been developed which permit dynamic measurement of stresses during and after welding through interpretive use of conventional strain gages. In this technique, interpretation of measurements rests upon application of the theory of beams on elastic foundations. Neither the method of measurement nor of analysis is sensitive to plastic occurrences in the immediate region of the weld.

2. Measurements and stress analyses indicate medium-carbon filler welds

performed on manganese-molybdenum armor plate can support a maximum stress of about 40,000 psi before cracking of the weld during cooling, and that low-carbon, low-alloy filler welds in the same base material can support a maximum stress of about 25,000 psi before cracking.

3. The maximum transverse distributed load which precedes cracking appears to be less dependent on welding conditions than upon filler composition.

4. Cracking of welds produced with low-carbon filler was accompanied by more plastic deformation and greater time delay than those produced with high-carbon filler.

APPENDIX I: Conversion of Strain-Gage Data Into Separating Forces and Bending Moments

In calibration, the strain gages are read under conditions of combined compression and bending of the material between gages. That portion of the stress, read on each gage, which is due to compression, can be subtracted algebraically from the reading, giving values which would prevail under conditions of pure bending:

$$S_1 - \frac{V}{A} = S_1^\circ \qquad (1)$$

$$S_2 + \frac{V}{A} = S_2^\circ \qquad (2)$$

where:

S_1, S_2 = absolute stresses read on the curved (compressive) and flat (tensile) strain gages, respectively.
S_1°, S_2° = absolute stress values due to bending alone.
V = applied force in calibration, or separating force in welding.
A = cross-sectional area of the metal between strain gages, the section taken perpendicular to the plate and parallel to the axis of welding.

Since, experimentally, S_1 and S_2 are observed to be in direct proportion to the applied calibration load (see Fig. 4), S_1° and S_2° are also proportional to the applied load and to the bending moment. The ratio, N, of S_1° to S_2° is, therefore, constant, and may be determined from the calibration data and eqs (1) and (2).

$$\frac{S_1^\circ}{S_2^\circ} = N \qquad (3)$$

Equations (1), (2) and (3) may be combined to give:

$$S_1^\circ = \frac{N}{N+1}(S_1 + S_2) \qquad (4)$$

$$\frac{V}{A} = \frac{S_1 - NS_2}{1+N} \qquad (5)$$

In order to separate bending and compression, the test section must be treated as a curved beam, in accordance with principles set forth by Timoshenko and MacCullough,[2] the neutral axis of the beam intersects the extended weld centerline at right angles. Since the "curved beam" is irregular, its effective radius of curvature and location of the neutral axis must be calculated from calibration data. Consider a curved beam of rectangular radial cross section; the radius of curvature, r, of the neutral axis is given by:

$$r = \frac{c-a}{\ln c/a} \qquad (6)$$

where c and a are distances to the outer- and innermost fibers of the beam, respectively, from the center of curvature. Under conditions of pure bending:

$$N = \frac{b_2 c}{b_1 a} \qquad (7)$$

where b_2 and b_1 are distances to the outer- and innermost fibers of the beam, respectively, from the neutral axis. Taking note of the relationships,

$$b_1 = r - a \qquad (8)$$

$$b_2 = c - r \qquad (9)$$

eqs (6) and (7) may be combined to give:

$$N = \left[\frac{W - (1 + \ln W)}{1 - W(1 - \ln W)}\right] W \qquad (10)$$

where:

$$W = c/a \qquad (11)$$

In the subject plate specimens, the distance, d, between strain gages is given by:

$$d = b_1 + b_2 \qquad (12)$$

Eliminating b_2 from eqs (7) and (12)

$$b_1 = \frac{d}{1 + (W/N)} \qquad (13)$$

The procedure in locating the neutral axis is: (*a*) determine N from calibration, (*b*) determine W using eq (10) and (*c*) determine b_1 from eq (13). The distance from the curved strain gage to the neutral axis is b_1.

With the location of the neutral axis known, the calibration data can be used to calculate the constant of proportionality, Z, between the bending moment at the neutral axis, M_0, and S_1°.

$$M_0 = ZS_1^\circ \qquad (14)$$

The bending moment at the inside end of the weld, M, is given by:

$$M = ZS_1^\circ - VY \qquad (15)$$

where Y equals distance to the neutral axis of the curved beam from the inside end of the weld.

In summary, the bending moment at the inside end of the weld and the total separating force are determined from the measured stresses S_1 and S_2 by: (*a*) using calibration data to determine N and Z, (*b*) calculation of b_1 from eqs (10) and (13), (*c*) calculation of S_1° from eq (4) and V from eq (5) and (*d*) calculation of M from eq (15).

APPENDIX II: Application of the Theory of Beams on Elastic Foundations

A. Semi-infinite Beams Under End-Load Conditions[19]

If a very long beam is joined to an elastic foundation and a direct upward load, V, and counterclockwise bending moment, M, are applied at the left-hand end, the tensile load distribution, $-q$, between the beam and its foundation, is given by:

$$-q = 2VJe^{-JX}\cos JX - 2MJ^2 e^{-JX} \times (\cos JX - \sin JX) \qquad (1)$$

where q has units of force per unit length, X = distance from end of beam at which loads are applied, and

$$J = \sqrt[4]{\frac{K}{4EI}} \qquad (2)$$

where:

K = elastic modulus of foundation, the force per unit length required to produce unit displacement of the entire beam.
E = modulus of elasticity.
I = moment of inertia of the beam cross section about the horizontal neutral axis.

For application to the subject plate specimens, the "beam" is the uniform member parallel to and joined with the weld, and is considered to be exactly as long as the weld itself.

$$\mathrm{I} = \frac{tb^3}{12} \qquad (3)$$

where:

t = plate thickness.
b = distance between the weld centerline and that edge of the plate to which it is parallel.

The elastic part of the foundation is considered to be that part of the "beam" between its neutral axis and the weld. Since the weld centerline is an axis of thermal and mechanical symmetry, it is not displaced. Any plastic deformation which merely causes the beams to become nonparallel does not contribute to the foundation modulus.

$$K = \frac{2tE}{b} \qquad (4)$$

Combining eqs (2), (3) and (4),

$$J = \frac{1.565}{b} \qquad (5)$$

At the end of the beam where forces are applied, the distributed load is the most severe:

$$-q_{x=0} = 2J(V - JM) \qquad (6)$$

B. Finite Beams Under End-Load Conditions

If the beam in question is of such length that the effects of forces or moments applied at one end are appreciably reflected at the other, the length, l, of the beam becomes a parameter of importance. In this case:

$$-\frac{q}{2I}\Big)_{x=0} =$$

$$V\left[\frac{\sinh J\,l\cosh J\,l-\sin J\,l\cos J\,l}{\sinh^2 J\,l-\sin^2 J\,l}\right]-$$

$$MJ\left[\frac{\sinh^2 J\,l+\sin^2 J\,l}{\sinh^2 J\,l-\sin^2 J\,l}\right] \quad (7)$$

The quantities in brackets are each greater than unity, but approach unity within 10% if the product, $J\,l$, exceeds 2.4, in which case eq (7) becomes nearly identical with the much simpler eq (6).

Acknowledgment

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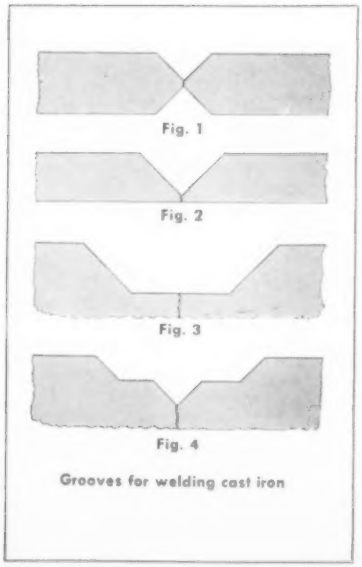
Cast iron is economical and useful for many purposes, despite the disadvantage of its low ductility. However, this low ductility is a major obstacle to success when fusion-welding is attempted for repairs, because shrinkage stresses often cause failure of the welds.

Oxyacetylene braze-welding with Anaconda-997 (Low-Fuming) Bronze and Tobin Bronze*-481 Welding Rods is widely accepted as the easiest and least expensive repair method. The reasons are 1) the low temperatures employed do not produce embrittlement or excessive stress in the joint area, and 2) the ductility of the bronze weld metal permits it to yield and prevents development of high stress.

Correct preparation of the fracture is necessary to realize all the advantages of braze-welding. As with all other welding processes, the break must be opened up to permit bonding of a sufficient thickness of the casting. Although the double-vee of Fig. 1 is the most economical in consumption of weld metal, and is often used when sections are not too heavy, the simplest preparation is the single-vee groove of Fig. 2. In either case, the bronze weld metal is applied to both sides for maximum joint efficiency. A small section of the fracture is left intact, as shown, to assist in lining up the parts.



Grooves for welding cast iron

In heavy sections which cannot be opened up for the full thickness, the area bonded by bronze can be increased, in order to develop higher joint strength, by use of the wide-bottomed vee of Fig. 3. The same results can be obtained, with use of less bronze, in the stepped-vee joint of Fig. 4.

Joints can be beveled by chipping, machining, filing, or grinding, in order of preference. Graphite smeared into the surfaces by grinding will interfere with bonding, but even ground surfaces can be used safely if they are first heated to a dull red with an oxidizing flame and wire-brushed thoroughly.

Oil on the joint surfaces will interfere with bonding, and should be removed. In most cases, a solvent will do this well enough. However, if heavily soaked, the castings should be preheated to temperatures between 600 and 1200F until most of the oil is removed, that is to say, when the smoking stops.

Preheating also facilitates welding on large castings where it is difficult to maintain the required heat level by means of the welding torch alone.

The most important function of preheat is to control expansion of components and avoid excessive stressing in complex castings like wheels, gears and frames. Where the whole casting is not heated, selected sections are heated to assist in opening up the fracture; then they shrink with the joint as it cools. Simple examples are shown in Fig. 5.

Fluxing is essential to insure proper bonding and sound joints. Suitable braze-welding fluxes are available from many sources. The flux should be sprinkled on the joint areas during the heating-up period. An efficient way to use flux is to dissolve it in boiling water and paint it lightly on the cleaned rods. It sticks well to the rods, keeps them from oxidizing, and eliminates the need to dip the rod end constantly in the dry flux.

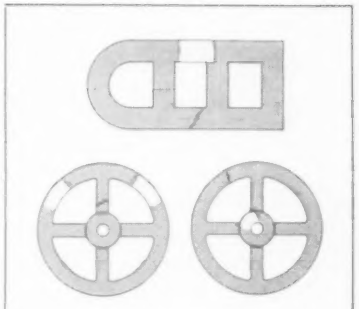


Fig. 5. Typical preheat locations

A slightly oxidizing flame adjustment is preferred. Torch-tip sizes should be selected so that the bronze melts and flows as required without having to apply the inner cone of the flame to the weld pool. The intense heat of this inner cone causes heavy fuming and severe oxidation of the joint surfaces. Prolonged heating, or "puddling," of the weld metal also should be avoided, as it wastes time and gases, and impairs the bond to the iron.

For More Information. Anaconda distributors will gladly help in the selection of the exact rod for your job. Or write for a copy of Publication B-13. Address: The American Brass Company, Waterbury 20, Conn. In Canada: Anaconda American Brass Ltd., New Toronto, Ont.

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